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GEOPHYSICAL FLUID DYNAMICS LABORATORY

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ACTIVITIES — FY84
PLANS — FY85

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
Environmental Research Laboratories

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GEOPHYSICAL FLUID DYNAMICS
LABORATORY
ACTIVITIES - FY84
PLANS - FY85

October 1984

Geophysical Fluid Dynamics Laboratory
Princeton, New Jersey

UNITED STATES
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Preface

This document is intended to serve as a summary of the work accomplished at the Geophysical Fluid Dynamics Laboratory (GFDL) and to present a glimpse of the near future direction of its research plans.

It has been prepared within GFDL and its distribution is primarily limited to GFDL members, to interested offices of the National Oceanic and Atmospheric Administration, and to other relevant government agencies and national organizations.

The organization of the document encompasses an overview, project activities and plans for the current and next fiscal years and appendices. The overview covers the five major research areas that correspond to NOAA's mission in oceanography and meteorology: Weather Service; Climate; Atmospheric Quality; Marine Quality; Ocean Service. These are five of the NOAA categories (bins) for research activities. The body of the text describes goals, specific recent achievements and future plans for the following major research categories: Climate Dynamics; Middle Atmosphere Dynamics and Chemistry; Experimental Prediction; Oceanic Circulation; Planetary Circulations; Observational Studies; Hurricane Dynamics; Mesoscale Dynamics; and Convection and Turbulence. These categories, which correspond to the internal organization of research groups are different from the NOAA bins and are far from being mutually exclusive. Interaction occurs among the various groups and is strongly encouraged.

The appendices contain the following: a list of GFDL staff members and affiliates during Fiscal Year 1984; a bibliography of the most recent research papers published by staff members and affiliates during their tenure with GFDL (these are referred to in the main body according to the appropriate reference number or letter); a description of the Laboratory's computational support and its plans for FY85; a listing of seminars presented at GFDL during Fiscal Year 1984; a list of seminars and talks presented during Fiscal Year 1984 by GFDL staff members and affiliates at other locations.

Although the specific names of individuals are not generally given in the overview, an entire listing of project participants can be found in Appendix A. Publishing staff personnel can normally be identified by consulting the cited Appendix B references.

The 1984 Annual Report was co-edited by Raymond T. Pierrehumbert and Betty M. Williams.

September 1984

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AN OVERVIEW

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SCOPE OF THE LABORATORY'S WORK

The Geophysical Fluid Dynamics Laboratory is engaged in comprehensive long lead-time research fundamental to NOAA's mission.

The goal is to expand the scientific understanding of these physical processes which govern the behavior of the atmosphere and the oceans as complex fluid systems. These fluids can then be modeled mathematically and their phenomenology studied by computer simulation methods. In particular, research is conducted toward understanding:

- the predictability of weather, large and small scale;
- the particular nature of the Earth's atmospheric general circulation within the context of the family of planetary atmospheric types;
- the structure, variability, predictability, stability and sensitivity of climate, global and regional;
- the structure, variability and dynamics of the ocean over its many space and time scales;
- the interaction of the atmosphere and oceans with each other, and how they influence and are influenced by various trace constituents.

The scientific work of the Laboratory encompasses a variety of disciplines: meteorology; oceanography; hydrology; classical physics; fluid dynamics; chemistry; applied mathematics; high-speed digital computation; and experiment design and analysis. Research is facilitated by the Geophysical Fluid Dynamics Program which is conducted collaboratively with Princeton University. Under this program, regular Princeton faculty, visiting scientists, and graduate students participate in theoretical studies both analytical and numerical, and in observational experiments, both in the laboratory and in the field. The program, in part, is supported by NOAA funds. Visiting scientists to GFDL may also be involved through institutional or international agreements, or through temporary Civil Service appointments.

The following sections of the Annual Report describe the GFDL contribution to five major research areas that correspond to NOAA's mission in oceanography and meteorology.

HIGHLIGHTS OF FY84

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IMMEDIATE OBJECTIVES

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In this section, some research highlights are listed that may be of interest to those persons less concerned with the details of GFDL research. Selected are items that may be of special significance or interest to a wider audience.

Items in this section are placed in the NOAA emphasis categories of Weather Service, Climate, Atmospheric Quality, Marine Quality, and Ocean Service. These categories are organized rather differently than the GFDL research project areas presented in the main body of the report. References to more detailed discussions are given in parenthesis.

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I. WEATHER SERVICE

During the past two decades synoptic-scale weather forecasts have improved considerably because of the development of numerical models that include more of the physical processes of the atmosphere, that have high spatial resolution, and that parameterize turbulent processes more accurately. Successful forecasts for periods up to a few days are now possible, and the limits of atmospheric predictability have been extended to several weeks; however, quantitative precipitation forecasts remain elusive. For smaller spatial scales, there has been considerable progress in determining the mechanisms that generate severe storms, in explaining how mesoscale phenomena interact with the large-scale flow, and in simulating the genesis, growth, and decay of hurricanes.

This success in the extension of atmospheric predictability encourages us to pose more challenging questions. Can the weather be predicted on time scales of months? Are mesoscale weather systems and regional scale precipitation patterns predictable, and if so, is the accuracy dependent on the prediction of the ambient synoptic flow? Research to develop mathematical models for improved weather prediction will also contribute to the understanding of such fundamental meteorological phenomena as fronts, hurricanes, severe storms, and tropospheric blocking.

ACCOMPLISHMENTS OVER THE PAST YEAR (FY84)

* Monthly forecast experiments carried out for 8 January cases with a GCM incorporating GFDL "E-physics" show that monthly forecasts appear feasible, though the current skill is marginal. The skill scores for 1000 mb geopotential height are higher than those for 500 mb height for all cases.

* Monthly forecasts using refined subgrid-scale parameterizations exhibit improved overall performance. The refined physics increases the capability of simulating blocking ridges and improves the prediction of geographical locations of planetary-scale waves. The root-mean-square geopotential height errors have distinct geographical distributions with respect to the models; these errors consist mostly of the climatic drift of the respective models. This suggests that further advances in monthly forecasting skill can be expected (3.2.1).

* A theory of the baroclinic instability of a zonally varying flow has been developed. This theory has implications for the relation of the positions of storm tracks to the large-scale planetary wave pattern, and for the role of transient eddies in the maintenance of large-scale anomalies (3.3.1).

* The continuous data insertion method in the GFDL four-dimensional data assimilation has been improved by applying a linear normal mode initialization to the injected data and using a wider range of data collection for determination of insertion data. There is an indication that such analysis improvements can yield improved long-range forecasts (3.4.2).

* The effects of a long mountain range on a landfalling hurricane were investigated. The mountain influences the distributions of the low level wind

and the precipitation intensity to a significant degree. The decay rate of the storm is increased as compared with a case excluding the mountain effects. The enhanced decay was associated with reduction of the convergence of latent and kinetic energy during the storm's passage across the mountain range. The mean easterly flow, which carried the vortex, was notably modified by the mountains and this influences the movement of the storm. This result adds another capability in the requirements for significant improvements in hurricane forecasting skill (7.1).

* A study on the evolution of a real hurricane was initiated with the preparation of a numerical model and real initial data. Hurricane David, 1979, was chosen for the first experimental case and initial fields were retrieved from the FGGE level III-b data set produced at GFDL. This is the first effort at GFDL to explore forecasting skill for real hurricanes (7.1 and 7.2).

* Simulations of an isolated shower cloud of one hour duration have been carried out with periodic and open lateral boundary conditions, with similar results. Using a continental sounding for moisture and temperature, a strong single cell develops which gives maximum precipitation of approximately 1.0 cm with rainfall lasting for one-half hour. The simulations indicate a significant model net vertical momentum flux which is downgradient in all instances. This suggests that GCM parameterizations of moist convection should include the effect of vertical momentum transfer (9.1.1).

* Results on the dynamics of atmospheric cold fronts in moist environments have clarified the role of latent heat in the frontal cross-stream circulation. It has been found that the classical idea on the differences between moist and dry fronts are probably not entirely correct. The analysis shows that the whole frontal circulation in a moist environment changes significantly, due to the weaker lapse rate as compared with a dry environment (8.1).

* A number of forecasts have been completed using the high resolution GFDL limited area model. Particular attention has been given to the simulation of a Pacific "Comma Cloud", a mesoscale convective system (MCS), two frontal squall lines, and a coastal cyclogenesis event. The results suggest that considerable success in forecasting dynamic meteorological variables can be obtained in spite of the rather poor quality of the quantitative precipitation forecasts (8.2.2).

* A meso-β scale simulation of a MCS over Oklahoma and Texas has produced a realistic simulation of precipitation and cloud patterns during the period 10-11 April 1979. It was found that insertion of observed wind and temperature data in the initial and boundary conditions has a major impact on the simulation (8.2.2).

* A 48-hr. simulation using a limited-area model nested in a global spectral model seems to have captured the explosive behavior of the Presidents's Day snow storm (February 19-29, 1979). The model data is now being analyzed to determine the mechanisms leading to the explosive storm growth (8.3).

PLANS FOR FY85

The effect of sea surface temperature anomalies on monthly forecasts will be investigated.

Nonlinear eddy fluxes of heat and momentum associated with local baroclinic instability will be derived. Local instability of realistic flows will be analyzed.

The newly designed hurricane model will be used to investigate the development processes of Hurricane David.

Investigations of the role of latent heat in frontogenesis will continue.

Detailed analysis of simulations of SESAME-I mesoscale convective systems will be carried out.

Investigations on the numerical simulation of deep continental convection will continue.

II. CLIMATE

The purpose of climate related research at GFDL is twofold: to describe, explain and simulate climate variability on time-scales from seasons to millenia; and to evaluate the climatic impact of human activities such as the release of CO_2 and other gases in the atmosphere. The phenomena that are studied include: large-scale wave disturbances, and their role in the general circulation of the atmosphere; the seasonal cycle, which must be defined before departures from the seasonal cycle (interannual variability) can be understood; interannual variability associated with phenomena such as the Southern Oscillation-El Niño; very long-term variability associated with the ice ages; and the meteorologies of various planets, the study of which enhances our perspective on terrestrial meteorology and climate. To achieve these goals, both observational and theoretical studies are necessary. Available observations are analyzed to determine the physical processes by which the circulations of the oceans and atmospheres are maintained. Mathematical models are constructed to study and simulate the ocean, the atmosphere, the coupled ocean, atmosphere and cryosphere system, and various planetary atmospheres.

ACCOMPLISHMENTS OVER THE PAST YEAR (FY84)

* A higher resolution (3° latitude) version of the GFDL "SKYHI" general circulation model has been integrated for more than 18 months. The improved horizontal resolution has led to a number of improvements in the simulated circulation. The higher quality model results include: improvements in tropospheric zonal winds and jet stream; planetary wave amplitudes and propagation to the stratosphere; onset of sudden stratospheric warmings; and a reduction in the model tendency to yield excessively cold stratospheric winter polar regions. These improvements allow a more detailed look into the model dynamics as well as into model sensitivity to climatic perturbations (2.2.6).

* Work is underway on understanding the effect of smaller-scale gravity waves on planetary waves in the stratosphere and mesosphere. Early results from this work indicate such interactions produce an important mechanism for mechanical dissipation of planetary wave energy. This discovery has important implications for our understanding of dynamics and transport in the middle atmosphere (2.2.8).

* An attempt has been made to simulate the climate of the last glacial maximum by use of a general circulation model of the atmosphere coupled with a mixed layer model of the ocean. Given the distributions of continental ice sheets and surface albedo and the reduced CO_2 concentration of the ice age, the model generates sea surface temperatures which compare favorably with the sea surface temperature at the last glacial maximum as reconstructed by geologists. When the same model is used for the study of the anticipated climate change due to a doubling of CO_2, it yields an increase of global mean surface air temperature of 2.2°C (1.3).

* It has been pointed out that the concentration of atmospheric carbon dioxide during the late Cretaceous epoch was several times higher than the modern concentration. To evaluate the climatic consequences of large changes in atmospheric CO_2, a series of numerical experiments were conducted for a wide variety of CO_2 concentrations (150 to 2400 ppm by volume) using a coupled ocean-atmosphere GCM with idealized geography. According to the results from these experiments, the high-CO_2 world is characterized by high surface air temperatures with smaller meridional gradients, higher deep sea temperatures, more intense hydrologic cycle, and a larger poleward moisture transport. These results suggest significant progress toward explaining the large differences between Cretaceous and contemporary climates. Moreover, they add credibility to current concerns on the possible climatic impact of increasing CO_2 (1.1.2).

* Numerical experiments are nearing completion that test the sensitivity of an idealized 9-level GCM to large decreases in solar constant. The qualitative dependence of sensitivity to solar constant changes has some similarity to previously published results with a 2-level model which differed significantly from the results predicted by the commonly used simple energy balance models (1.2).

* Work is continuing on the comparison of stationary eddies produced by GCM's with the eddies predicted by a linear model based on the primitive equations. It has been demonstrated that a useful first approximation to the stationary eddy field in the extratropical upper troposphere can be obtained with such a linear model. (1.4.1a). This suggests that significant improvements in the theoretical understanding of stationary eddies in the atmosphere may be forthcoming.

* An analysis of the structure of stationary Rossby waves in vertical shear has been completed which explains why the response to stationary forcing in the troposphere is equivalent barotropic far from the source and why there tends to be a maximum in geopotential amplitude near the tropopause (1.4.1b).

* Calculations with an idealized 2-layer quasi-geostrophic model show that the eddy heat and potential vorticity fluxes increase much less rapidly as the meridional extent of the unstable region increases than is predicted either by

weakly non-linear theory or by the popular "baroclinic adjustment" hypothesis (1.4.2b).

* Spectral analysis of results from GCM calculations indicates that stationary ultralong waves gain kinetic energy but lose available potential energy through the nonlinear interaction with transient waves. This loss is much larger than the gain and is compensated by a zonal to eddy conversion of available potential energy (1.4.2c).

* Calculations of infrared radiative cooling rates using line-by-line methods have begun. These will be used as international standards against which the results of the parameterized algorithms employed in GCM's can be compared. This is part of the WMO-sponsored International Comparison of Radiation in Climate and Circulation Models (1.5.3).

* Two extensive tape libraries with global atmospheric and oceanographic analyses were prepared for distribution to the scientific community by the National Climatic Data Center and the National Oceanographic Data Center, respectively (6.1.1 and 6.2.1).

* An extensive compilation of monthly general circulation statistics based on the FGGE level III-B analyses produced at GFDL and a comparison with the ECMWF analyses for the Special Observing Periods were published as NOAA Data Reports (6.1.1).

* A 15-year GCM run with changing sea surface temperatures prescribed according to observations in the Pacific between 30°S and 30°N gave an excellent simulation of the El Niño-Southern Oscillation phenomena in the atmosphere, especially in the tropics. This result lends optimism that properly coupled atmosphere-ocean model will be able to simulate these phenomena. A clear impact of such events was found on the midlatitude circulation (Pacific-North American pattern) during northern hemisphere winter (6.1.4).

* The observed anisotropy in transient disturbances with various time scales was found to be an important factor in determining the nature of the local exchange of kinetic energy between eddies and the time-mean flow (6.1.2).

* In order to balance the poleward flow of angular momentum in the atmosphere, it was concluded from observational evidence that the return flow of angular momentum from middle to low latitudes does not occur in the oceans, but rather in the solid earth (6.1.2).

* Observational evidence was found for a meridional divergence or source of water vapor over land as well as both oceans in the subtropics of the Northern and Southern Hemispheres. This "land source" of water is supplied by east-west convergence from the oceans (6.1.3).

* The birth of Jupiter's Great Red Spot (GRS) has been simulated by a model that describes the weak solitary barotropic instabilities that act at the large planetary scales. The longevity of the GRS has been simulated by a large vortex that appears to last indefinitely.

PLANS FOR FY85

The basic 15-year (1958-1973) and FGGE (1979) data sets will be used to evaluate regional balances of angular momentum, energy, and water vapor.

The FGGE analyses generated at GFDL will be used in a study of the diurnal cycle of the atmosphere.

Model simulations of meteorological phenomena accompanying the El Niño-Southern Oscillation will be compared with observation.

A global model of the coupled ocean-atmosphere system with high computational efficiency will be constructed for the study of climate sensitivity. The performance of this model will be tested extensively (1.5).

Effort to identify and isolate the causes of systematic biases in current spectral and finite difference general circulation models will be underway with continued emphasis on improvements in model physical processes (1.5.4 and 2.2.1).

The study of the transient and equilibrium response of climate to an increase of atmospheric carbon dioxide will be continued by use of a coupled ocean-atmosphere model with limited computational domain and idealized geography (1.1).

The influence of cloud radiation feedback processes upon the sensitivity of climate will be investigated by use of a global atmospheric GCM coupled with a mixed layer ocean model (1.1).

To identify the physical factors responsible for the cold climate of an ice age, additional numerical experiments with an atmosphere-mixed layer ocean model will be conducted and analyzed (1.3).

Analyses of the albedo-feedback experiments with an idealized GCM will continue. Attention will be focused on the factors that determine how far equatorward the snowcover boundary must be before the model experiences a rapid increase in sensitivity (1.2).

Studies with linear primitive equation models on a sphere will continue. The extent to which the linear model can simulate the seasonal cycle in planetary wave structure will be examined. An attempt will be made to simulate the extratropical anomalies in extended GCM integrations with observed Pacific SST's. The same GCM integration will be used to test the ability of a simple linear viscous model of the low-level tropical flow to simulate the anomalous flow due to SST anomalies in the Pacific (1.4.1).

Simple linear and nonlinear models of the tropical upper tropospheric flow and interactions between this flow and extratropical eddies propagating into low latitudes will be examined, with particular attention to the possibility of reflection of incident Rossby waves by tropical winds (1.4.1).

A space-time spectral analysis will be made of the low frequency oscillations in the tropics simulated by a spectral general circulation model.

A set of experiments will be made by the use of a simplified general circulation model to study the effects of transient waves on the zonal mean flow in the presence of surface friction (1.4.2).

The results of the International Radiation Model Comparison study will be analyzed, with the goal of improving the radiative parameterization in GFDL GCM's (1.5.3).

Analysis will be underway on the dynamical behavior of the (3° resolution) SKYHI model including sudden stratospheric warming diagnosis, impact of gravity waves on planetary waves, and identification of satellite sampling errors (2.2).

III. ATMOSPHERIC QUALITY

GOALS

The main goal of Atmospheric Quality Research at GFDL is to understand the formation, transport, and chemistry of atmospheric trace constituents. Such understanding requires judicious combinations of theoretical models and specialized observations. The understanding gained will be applied toward evaluating the sensitivity of the atmospheric chemical system to human activities.

Ongoing work that will be completed within the next 5 years includes analyses of atmospheric nitrous oxide, reactive nitrogen (natural plus anthropogenic), and tropospheric ozone. Capability will be developed to solve for a number of trace constituents simultaneously. Using this capability, interdependent experiments will be run involving ozone and its precursors, partitioned components of total reactive nitrogen, carbon monoxide, etc. Also, development of a dynamically active ozone photochemistry will be completed for inclusion into the GFDL troposphere-stratosphere-mesosphere GCM. In addition, this model will be developed for passive tracer studies.

ACCOMPLISHMENTS OVER THE PAST YEAR (FY84)

* A simple model has been developed which illuminates the mechanisms leading to the observed poleward-downward meridional slopes of stratospheric trace constituents. In particular, the quantitative role of chemical processes in "flattening" these slopes has been clarified. The theory also predicts the way that the global average vertical "eddy diffusion" coefficient varies as a function of chemical sources and sinks (2.1.1).

* By keying off the above results, a simple model has been developed which predicts the structure of trace constituent temporal variability given a particular chemistry. These two results allow the possibility of predictions of time mean and variable trace constituent structure given such knowledge for one constituent and the appropriate chemistry for any other constituent. If such predictions prove to be valid upon observational testing, the problems of modeling systems with many species should be substantially simplified (2.1.1).

* The vertical mixing of a passive tracer initially confined to the boundary layer has been examined. For long-lived convection a well defined

inflow-outflow circulation develops so that mixing through a depth of 5 km is much stronger than for a short duration shower cloud. Tentative results show small mixing in the upper troposphere. A primary conclusion is that vertical mixing appears strongly dependent on the duration of the convective cells (9.1.3).

PLANS FOR FY85

Efforts will continue on the "combustion nitrogen" and tropospheric ozone series of numerical experiments, with emphasis on greater realism.

Work will be initiated on multiple, interactive trace constituent modeling.

A more detailed analysis of the convective transport of a passive tracer will be underway, with an exploration of the effects of a water solubility included.

IV. MARINE QUALITY

GOALS

Research at GFDL related to the quality of the marine environment has as its objective the simulation of oceanic conditions in coastal zones and in estuaries, and the modeling of the dispersion of geochemical tracers (tritium, radon...) in the world oceans. Over the next few years, two and three-dimensional models of estuaries such as the Hudson-Raritan and Delaware Estuaries will be developed. The response of coastal zones to transient atmospheric storms, and the nature of upwelling processes which are of great importance to fisheries, are being studied by means of a variety of models.

ACCOMPLISHMENTS FY1984

* A time dependent carbon cycle model has revealed that the response time of atmospheric carbon dioxide to changes in the oceanic circulation is on the order of 200 years. This discovery may explain the low carbon dioxide amounts during the last ice age, as well as provide an important feedback mechanism on the current fossil fuel increase in carbon dioxide (4.2).

* Analysis of transient tracer data and supporting modeling efforts have shown that seasonal convection and isopycnal mixing dominate over Ekman pumping in thermocline ventilation. This suggests that simulations of seasonal and high latitude processes must be especially accurate to produce good models of oceanic tracer transport (4.2).

PLANS FOR FY85

Work on the global carbon cycle will be extended by combining the existing geochemical model with a detailed three-dimensional model of the ocean circulation.

V. OCEAN SERVICE

GOALS

A variety of models that can be used for the prediction of oceanic conditions are being developed at GFDL. The simpler models are capable of predicting relatively few parameters. For example, one-dimensional models of the turbulent surface layer of the ocean predict the sea surface temperature and heat content of the upper ocean. More complex three-dimensional models are being developed to study phenomena such as the time dependent development of Gulf Stream meanders and rings, the generation of the Somali Current after onset of the southwest monsoons, the response of coastal zones to atmospheric storms, and the development of sea surface temperature anomalies such as those observed in the tropical Pacific Ocean during El Niño-Southern Oscillation phenomena.

ACCOMPLISHMENTS OVER THE PAST YEAR (FY84)

* A high resolution model of the tropical oceans has been developed and used for realistic simulations of the seasonal cycle in the tropical Atlantic and of the 1982-1983 El Niño event. Of particular interest is the result that an intensification of the North Equatorial Countercurrent, between 5°N and 10°N, was responsible for a large part of the eastward transfer of warm surface waters in the Pacific in 1982 and 1983. This result, using observed surface winds for forcing, offers encouragement that coupled atmosphere-ocean models may successfully simulate the El Niño phenomenon.

* An eddy resolving model of the ocean including both the effects of wind and thermal driving has been developed. An analysis of the solutions shows an extensive mixing along isopycnal (constant density) surfaces. This process is absent in lower resolution models. Eddy transport of heat is a small, but significant component of the total poleward transport of heat by ocean currents. This has an important bearing on the design of ocean models for climate studies. In contrast to the atmosphere, the model indicates that oceanic eddy heat transport may be largely equatorward rather than poleward.

* New observational evidence was found for the reality of a large annual cycle in the oceanic heat transport (6.1.2).

PLANS FOR FY85

Detailed comparisons between measurements of the seasonal cycle in the tropical Atlantic and model simulations will be undertaken (4.1.1).

The mass and heat budgets of the seasonal cycles of the tropical Atlantic and Pacific Oceans, and of the 1982-83 El Niño event, will be studied to determine how heat and mass transports in the ocean change seasonally and interannually (4.1.2).

The resolution of the global general circulation model will be improved, and tests carried out to determine the rate of water mass formation (4.3).

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1. CLIMATE DYNAMICS

Goals

* To construct mathematical models of the atmosphere and of the joint ocean-atmosphere system which simulate the global large-scale features of climate.

* To study the dynamical interaction between large-scale wave disturbances and the general circulation of the atmosphere.

* To identify and elucidate the physical and dynamical mechanisms which maintain climate and cause its variation.

* To evaluate the impact of human activities on climate.

1.1 CO_2 and CLIMATE

K. Bryan	R. J. Stouffer
S. Manabe	R. T. Wetherald
M. J. Spelman	

ACTIVITIES FY84

1.1.1 Hydrologic Response

During the last several years, the response of hydrology to an increase of atmospheric CO_2 has been the subject of continuous investigation by the Climate Dynamics Project. The model used for this research has been an atmospheric general circulation model coupled with a static mixed layer model of oceans. The response of the model climate to an increase in CO_2-concentration of the atmosphere has been evaluated by comparing two quasi-equilibrium climates which emerge from the long term integrations of the model with normal and above normal CO_2-concentrations.

One of the serious difficulties encountered stems from the fact that the signal of the CO_2-induced change in hydrology is often obscured by noise, e.g., natural variability of the model hydrology. Recently, an attempt has been made to overcome this difficulty by extending substantially the period of numerical time integration and, accordingly, the period of time averaging for determination of the equilibrium climate of the model. (The averaging period was extended from 3 to 10 years.)

Figures 1.1a and 1.1b illustrate the latitude-month distributions of the changes in zonal mean soil moisture which occur in response to doubling and quadrupling the CO_2 concentration in the model atmosphere. According to this figure, the general features of the change of soil moisture resulting from CO_2-doubling are qualitatively similar to the corresponding change due to CO_2 quadrupling. These features include enhanced soil dryness in summer and increased soil moisture during winter in middle and high latitudes, and reduced soil moisture during winter in the subtropics. It is encouraging that these changes are in qualitative agreement with the results from the earlier GFDL studies in which the length of numerical time integration was much shorter.

The model used for the studies described above has a prescribed distribution of cloud cover. These results may be compared with those from another version of the model in which cloud cover is predicted as a function of relative humidity in the atmosphere. Fig. 1.1c illustrates the latitude-month distribution of zonal mean change of soil moisture from the model with predicted cloud cover. Again, one notes the distribution of CO_2-induced change with qualitatively similar characteristics. The physical mechanisms responsible for these CO_2-induced changes of soil moisture are extensively discussed in a recent review article (ay).

1.1.2 Paleoclimate and CO_2

Recent results from a computer model of the geochemical cycle suggest that the atmospheric CO_2-concentration during the Cretaceous epoch (65 ~ 100 My

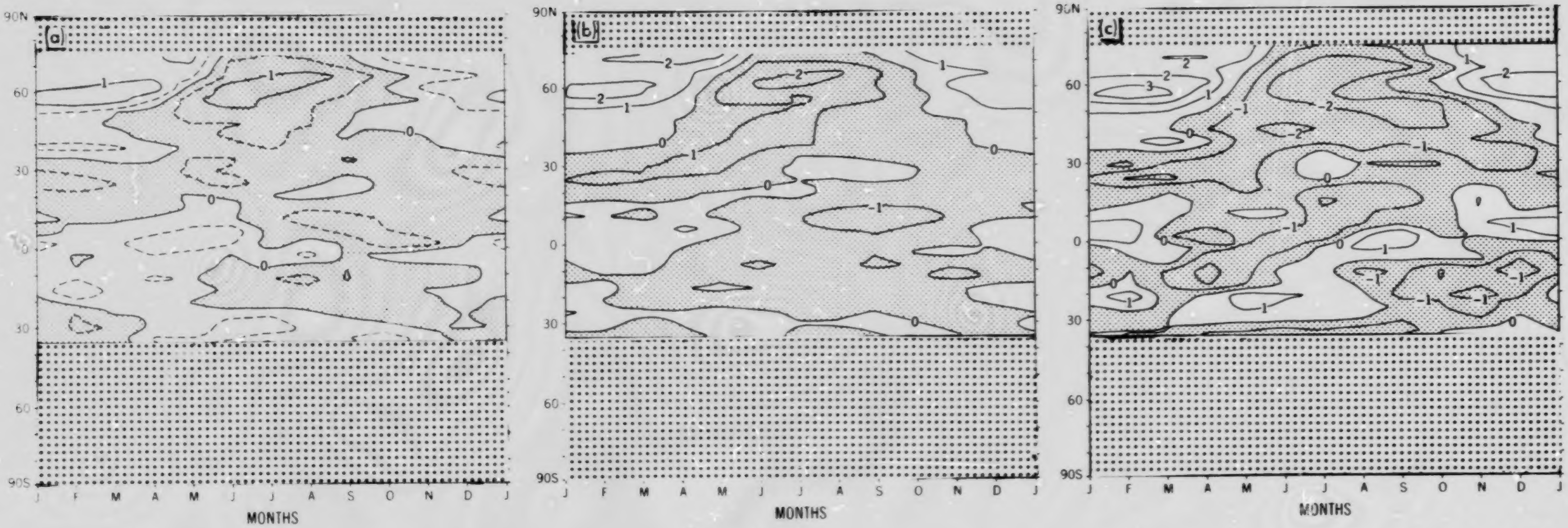

Fig. 1.1-- The latitude-month distributions of CO_2-induced change in zonal mean soil moisture (cm) from the atmosphere-mixed layer ocean model.

(a) change due to the doubling of atmospheric CO_2 (from the model with fixed cloud cover).
(b) change due to the quadrupling of atmospheric CO_2 (from the model with fixed cloud cover).
(c) change due to the quadrupling of atmospheric CO_2 (from the model with predicted cloud cover).

B.P.) was several fold higher than the modern concentration (Berner et al., 1983).[†] On the other hand, chemical analysis of air bubbles trapped in the Antarctic and Greenland ice sheets suggests that the atmospheric CO_2 concentration was half as large as the modern concentration at the last glacial maximum (18 K B.P.).[††] In order to evaluate the climatic impact of such a large alteration in the CO_2-concentration, the quasi-equilibrium climates of a deep ocean-atmosphere model are obtained for several different concentrations of CO_2 (i.e., 150, 300, 600, 1200 and 2400 ppm). The coupled model used for this series of experiments has a limited computational domain (i.e., 1/3 of one hemisphere) and an idealized sector geography which consists of a pie-shaped continent and ocean.

According to the results of these numerical experiments, the high CO_2 (2400 ppm) world is characterized by high surface air temperatures with small meridional gradients, high deep sea temperatures, intense hydrologic cycle and large poleward moisture transport in middle latitudes. Most of these features are in qualitative agreement with the geological manifestations of the Cretaceous climate. It is of particular interest that the CO_2-induced warming of the deep sea is as large as the corresponding warming of surface water in high latitudes where relatively cold water sinks to form deep water of the model ocean.

At the other extreme, the low CO_2 (150 ppm) world is characterized by extremely low surface air temperature in the polar region, whereas surface water temperature of the model ocean is constrained by sea ice near the freezing point in high latitudes. The lack of a meridional temperature gradient in high latitudes is responsible for a weak thermohaline circulation in the low CO_2 experiment.

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The results from a long term integration of the global atmosphere-mixed layer ocean model will be analyzed in detail in order to determine the geographical distribution of the CO_2-induced change in hydrology.

The analysis of the results from the coupled ocean-atmosphere model with very large or small CO_2 concentration will be continued. The paleoclimatic implication of these results will be evaluated.

The study of equilibrium and transient responses of climate will also be conducted by use of a coupled ocean-atmosphere model with higher computational resolution.

[†] Berner, R.A., A.C. Lasaga, and R.A. Garrels, 1983: The carbonate-silicate geochemical cycle and its effect on atmospheric carbon dioxide over the past 100 million years. American Journal of Science, 283, 641-683.

[††] Neftel, A., H. Oeschger, B. Stauffer, and R. Zumbrunn, 1983: In core sample measurements give atmospheric CO_2 content during the past 40,000 yr., Nature, 295, 220-222.

1.2 SENSITIVITY OF A GCM TO THE SOLAR CONSTANT

I. M. Held P. Phillips
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Calculations are being performed testing the sensitivity of an idealized nine-layer atmospheric GCM to large decreases in solar constant (Q). For efficiency, symmetry about the equator and three-fold symmetry around a latitude circle are assumed. The model has a "swamp" (saturated, zero heat capacity) surface and cloudiness is prescribed, but surface albedos are allowed to increase as temperatures drop below freezing to account for increasing snowcover.

Simple energy balance models generally predict monotonically increasing sensitivity (∂(global mean surface temperature)/∂Q) as Q decreases, owing to stronger albedo feedback. The two-layer primitive equation model described in (323) predicts an initial rapid increase in sensitivity as Q is lowered. (Importantly, the analogous constant diffusivity energy balance model does not reach comparable sensitivities until much lower values of Q). The sensitivity reaches a maximum and then dips to a minimum after the snowcover boundary passes through the midlatitude maximum in baroclinic activity; after this, the sensitivity increases again, leading finally to the familiar large-icecap instability. This behavior was explained in (468) as due to aspects of the response of the model's poleward energy flux to the expanding snowcover that are not captured in the simplest energy balance models. The current GCM calculations are designed to see if this behavior persists in a more comprehensive model.

The numerical experiments are nearing completion. The results appear to be similar to those in the two-layer model for small reductions in Q. In particular, the rapid sensitivity increase again occurs for rather small ice caps. The dip in sensitivity for colder climates does not seem to be present, although there is a plateau in $\partial T/\partial Q$ before the final instability sets in. Analysis is beginning of the model's energy fluxes, and an energy balance model is being designed to clarify which aspects of the flux responses to changes in Q are essential for understanding the GCM's sensitivity.

In support of these calculations, we have also examined the response to Q variations in the same model, but with fixed surface albedos. Experiments were performed at a standard value of Q and at values 10% smaller and larger. An unexpected result was obtained in the -10% calculation: the tropospheric jet moved poleward by more than 10° latitude. Little movement was observed in the +10% case. To check the robustness of this result, we have repeated these calculations with a global model (removing the restriction to symmetry about the equator) with a full zonal spectrum (removing the three-fold symmetry). No large shift in the jet was observed as Q was lowered 10% in this model.

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Analysis of the albedo-feedback experiments with an idealized GCM will continue, and comparisons will be made with a variety of energy balance models. Attention will be focused in particular on the factors that determine how far equatorward the snowcover boundary must be before the model experiences a rapid increase in sensitivity.

An attempt will be made to understand why different models produce very different zonal wind responses when the solar constant is lowered 10% with fixed surface albedos. The responses in models with (1) three-fold symmetry around latitude circles but without the equatorial wall and, (2) a full zonal spectrum but with an equatorial wall, will also be examined.

1.3 SIMULATION OF AN ICE AGE CLIMATE

A. J. Broccoli S. Manabe

ACTIVITIES FY84

During the last several years, the Climate Dynamics Group has continued to evaluate the factors which are responsible for maintaining the cold climate of an ice age. A manuscript, which discusses the influence of a massive continental ice sheet upon the climate of an ice age, has been completed and submitted for publication (aw).

Recently, an attempt has been made to simulate the climate of the last glacial maximum which took place approximately 18,000 years before the present (18K B.P.). The model used here is an atmospheric general circulation model coupled with a static mixed layer ocean model. A simulated climate is obtained from a long term integration of the model which assumes the 18K B.P. distribution of continental ice and surface albedo and a reduced atmospheric CO_2 concentration (i.e., 200 ppm by volume). Figure 1.2 illustrates the latitudinal distribution of the annually averaged, zonal mean difference in sea surface temperature (SST) between this 18K B.P. and modern model climates. For the sake of comparison, the corresponding difference in SST as determined from the analysis of fossil plankton assemblages contained in deep sea cores (CLIMAP, 1981) is also added to the same figure. This comparison indicates that the model overestimates the difference between the 18K B.P. and modern SST in the subtropics. Nevertheless, it yields an annually averaged, global mean SST-difference of 2.0°C which is only slightly larger than the difference of 1.6°C obtained by CLIMAP.

The results described above encourage one to use a similar model for the study of the climatic response to an increase of CO_2 concentration in the atmosphere. According to the results from another recent study conducted by use of this model, the equilibrium response of the global mean surface air temperature in response to the doubling of the CO_2 concentration in the atmosphere is about 2.3°C. This result lies in the lower half of the estimate of 1.5 to 4.5°C in the recent reports from the National Academy of Sciences.

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The results from the Ice Age simulation experiment with the atmosphere-mixed layer ocean model will be analyzed in detail. Additional

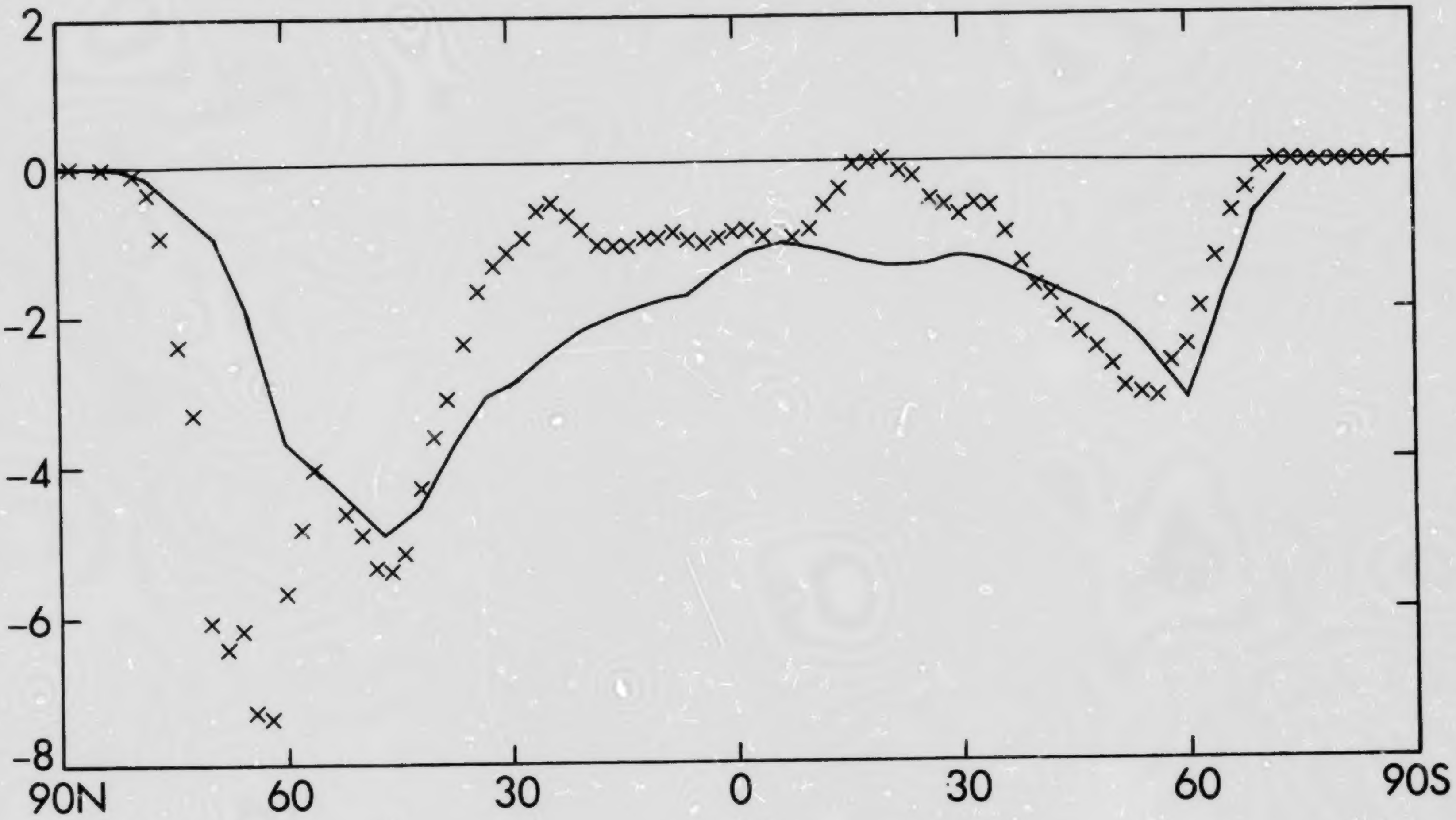

Fig. 1.2-- Latitudinal distributions of annually averaged zonal mean SST difference between 18K B.P. and modern climates. The solid line represents the results from the atmosphere-mixed layer ocean model, and the crosses are "observed" data based on the CLIMAP reconstruction of the 18K B.P. climate. (For the CLIMAP data, the annual mean is represented by an average of the February and August SST differences.)

numerical experiments will also be conducted in order to evaluate the individual contributions of various physical factors (i.e., surface albedo, atmospheric CO_2 concentration, and continental ice sheets) in maintaining the cold climate of an ice age.

1.4 WAVE DYNAMICS AND CLIMATE

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I.-S. Kang	R. L. Panetta
N.-C. Lau	R. T. Pierrehumbert
S. Lyons	

ACTIVITIES FY84

1.4.1 Stationary Eddies

(a) Linear primitive equation model

Work is continuing on the comparison of the stationary eddies produced by GCM's with the eddies predicted by a linear model based on the primitive equations. The zonally symmetric basic state, the orography, and the total diabatic heating field used in the linear model are all taken directly from the GCM. It has been demonstrated that a useful first approximation to the stationary eddy field in the extratropical upper troposphere can be obtained with such a linear model. The question as to whether this simulation is adequate to allow one to decompose the eddy field into parts forced by the individual major mountain complexes, by extratropical heating, and by tropical heating, is being actively pursued. One of the major problems is that large damping is required in the tropics of linear models in order to obtain plausible tropical eddies. In (535) it is argued that this damping crudely accounts for neglected nonlinearity. Unfortunately, the damping also controls the amplitude of the extratropical stationary waves forced by the tropical heating. In the linear model we tune the damping to obtain the correct amplitude for the tropical response and hope that the amplitude of the waves emanating from the tropics is then also correct.

(b) Stationary external Rossby waves

A manuscript on the structure of stationary external Rossby waves in vertical shear was completed and submitted for publication (ba). This work explains why the response to stationary forcing in the troposphere is equivalent barotropic far from the source and why the resulting equivalent barotropic wave has maximum amplitude at the tropopause. It is also shown that the rigid lid in GCM's does not produce artificial stationary resonances, at least for typical wintertime conditions.

This work has led us to study the effects of dissipation on stationary external Rossby waves in vertical shear. The counter-intuitive result is obtained that many kinds of "dissipation," in particular, thermal damping below the tropopause and potential vorticity diffusion near the surface, actually result in downstream amplification of the stationary waves, rather than decay. This result may help in understanding how stationary wavetrains can pass through regions of intense mixing by transient eddies without being destroyed. Calculations are in progress to evaluate the strength of these effects.

(c) Tropical models

A simple linear viscous model of the low-level tropical flow forced by evaporation is under development. The flow is driven by latent heat release, the low level moisture field is advected by this flow, and the precipitation field is predicted. The dependence of the results on the criteria for precipitation is currently being examined. Plans are underway to determine the extent to which this simple model can mimic the responses of a GCM to anomalous sea-surface temperatures, using the extended integrations described in Sec 6.1.

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Analysis of the linear primitive equation model on a sphere will continue, particularly with regard to its sensitivity to tropical damping and to details of the zonal flow. The extent to which the linear model can simulate the seasonal cycle of stationary eddies will be examined. An attempt will also be made to simulate the extratropical anomalies in the extended GCM integrations with observed Pacific SST's (Sec. 6.1) in the hope of distinguishing between the various theories that have been proposed to explain these wave-like features.

The same GCM integration will be used to test the ability of a linear viscous model of the low-level tropical flow to simulate the anomalous flow field resulting from anomalous SST's over the tropical Pacific. (See Sec. 6.1 for planned coupled ocean-atmosphere studies using this atmospheric model.)

The difficult problem of the nonlinear stationary response to tropical forcing will be examined with idealized barotropic and baroclinic models. The possibility will be examined that the position and strength of the summertime Tibetan anticyclone can be plausibly explained by a nonlinear barotropic model in which the advection of vorticity by the divergent flow is included.

Work will also continue on the excitation and dissipation of external Rossby waves in vertical shear.

1.4.2 Wave-Mean Flow Interaction

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R. L. Panetta
P. Phillips

ACTIVITIES FY84

(a) Rossby wave - Hadley cell interaction

The strength of the subtropical jet can be thought of as determined by competition between poleward flow in the Hadley cell, which attempts to conserve angular momentum and spin up the jet, and extratropical eddies propagating into low latitudes where they decay, thereby generating an eddy momentum flux divergence. A simple, heuristic model of this competition has been constructed by coupling an idealized Hadley cell model with a barotropic model of the upper tropospheric momentum fluxes due to Rossby wave dispersion. A manuscript describing both models has been completed, and will be submitted for publication shortly. The Hadley cell model can be either "moist" or "dry." Preliminary results suggest that this is a promising way of studying the maintenance of winds and vorticity gradients equatorward of the subtropical jet and the possibility of reflection by tropical winds of incident Rossby waves.

(b) Finite amplitude baroclinic instability

Work has continued with a highly idealized two-layer, quasi-geostrophic, wave-mean flow interaction model of equilibrated baroclinic instabilities. This work is motivated by the conjecture in (438) that, in the limit in which the unstable region is much wider than the Rossby radius of deformation ($<\lambda_R$), the eddy statistics will become horizontally homogeneous, so that powerful techniques developed for homogeneous turbulence can be brought to bear on the baroclinic eddy flux parameterization problem. As an example of results being obtained, Fig. 1.3 shows the time-averaged eddy potential vorticity flux in the upper layer of a model in which the unstable region forced by thermal damping is centered at $y = o$ and has width W. Results for W = 5, 10, 20, 40, and 80 λ_R are plotted. The flux is apparently equilibrating and a region of homogeneous statistics developing as W increases. The fact that the flux in this homogeneous limit is only a factor of ≈ 3 larger than the flux produced for a modest width of 5 λ_R suggests that the dynamics in this limit may not be dramatically different from that in relatively narrow unstable regions. Both weakly nonlinear theory and the popular "baroclinic adjustment" hypothesis predict that the flux is proportional to W^2, in obvious disagreement with these calculations.

(c) Stationary-transient planetary wave interaction

A wavenumber spectral analysis has been made of the nonlinear energy transfer between the tropospheric stationary and transient waves in the midlatitudes simulated by a GFDL 9-level spectral general circulation model with 30 zonal wavenumbers (az). It was found that the simulated wavenumber energy spectra compared favorably with those observed. In particular, both simulated and observed ultralong waves were maintained primarily by energy transfer from zonal available potential energy. The model's energy spectra were then partitioned into stationary and transient wave parts. It was found that stationary ultralong waves gain kinetic energy but lose available potential energy through the nonlinear interaction with transient waves. This loss was much larger than the gain and was compensated by an eddy energy conversion of the zonal available potential energy. On the other hand, transient ultralong waves gained both kinetic and available potential energy through wave-wave interactions. This gain was, however, not larger than the gain from the zonal available potential energy.

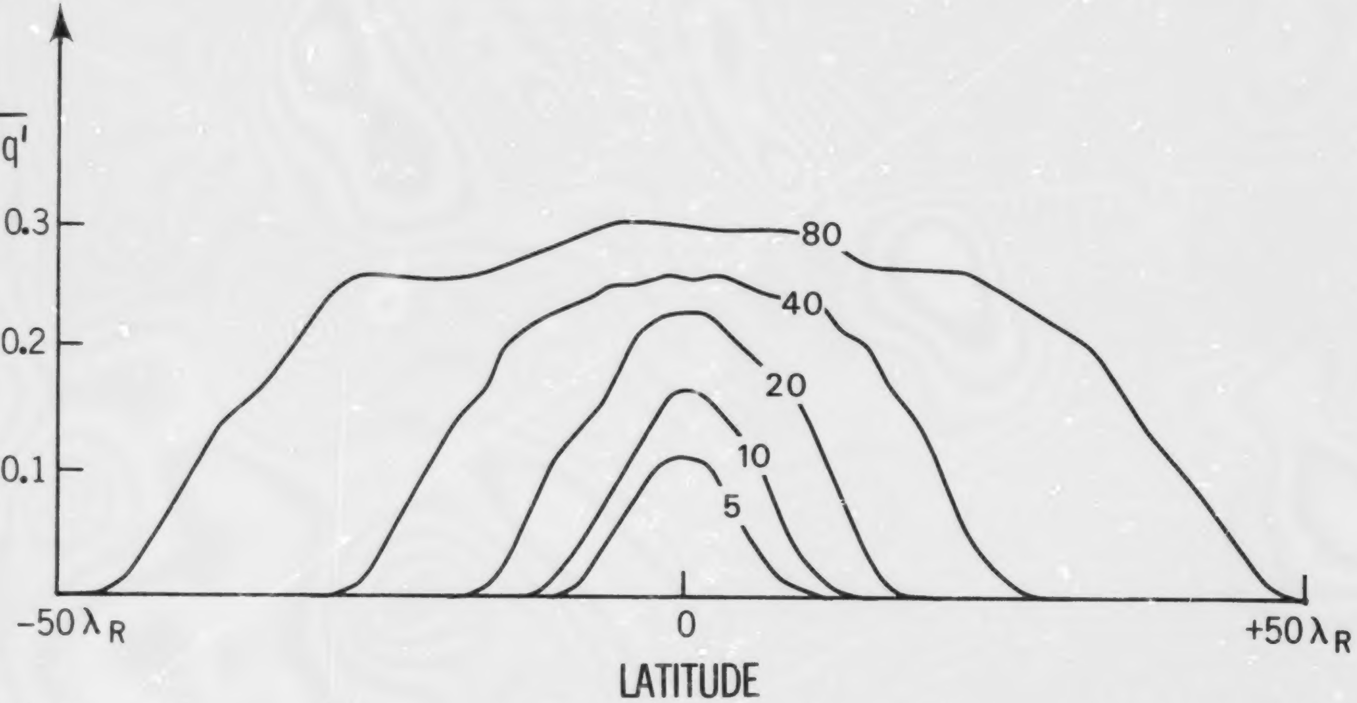

Fig. 1.3--Upper layer potential vorticity flux in a two layer quasi-geostrophic model truncated to one non-zonal wavenumber plus the zonal flow, but with high meridional resolution. In the absence of eddies the zonal thermal wind relaxes to u(y), which has a form such that the flow satisfies Phillips' criterion for instability in a region of width W centered at y=o. Different lines in the figure corresponding to different values of W. The flux is non-dimensionalized by $(u(o))^2\lambda_R^{-1}$.

(d) Wave-zonal flow interaction

In order to interpret the Eliassen-Palm diagnostics of wave-mean flow interactions theoretically, necessary and sufficient conditions were derived for Eliassen-Palm (E-P) flux divergence to approximate the zonal acceleration in the absence of mean damping (ax). Although this approximation holds for vertically large-scale mean flow, it does not always hold for vertically large-scale E-P flux divergence. The violation of these conditions accounts for the reason why some observational diagnostic studies indicate that transient eddies accelerate westerlies in the mid-latitude upper troposphere, although the transient E-P flux divergence is easterly there. Nevertheless, simple diagnostic relations show that the steady state westerlies in the upper troposphere can be reduced by eddies in the presence of surface friction. This is due to the fact that eddies accelerate the surface westerlies and in turn enhance frictionally induced indirect mean meridional circulations which decelerate the upper westerlies due to the Coriolis effect.

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Both the Rossby wave - Hadley cell model and the finite amplitude baroclinic instability model will be analyzed in detail in the coming year. A space-time spectral analysis will be made of the low frequency oscillations in the tropics simulated by a spectral general circulation model.

Controlled experiments will be made, through the use of a simplified general circulation model, to study the effects of transient waves on the zonal mean flow in the presence of surface friction.

1.5 MODEL DEVELOPMENT

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M. J. Spelman
S. B. Fels
M. D. Schwarzkopf
R. J. Stouffer
R. T. Wetherald

ACTIVITIES FY84

1.5.1 Coupled Ocean Atmosphere Model

Improvement of the coupled ocean-atmosphere model has been one of the major objectives of the collaborative effort between the Climate Dynamics and the Ocean Circulation projects at GFDL. During this fiscal year, the performance of a coupled model with improved computational resolution has been tested. The model has a limited computational domain and idealized geography. Annual mean insolation is assumed at the top of the model atmosphere. In the atmospheric component of the model, the fields of prognostic variables are represented by a finite number of spherical harmonics which are truncated rhomboidally at wavenumber 30. In the oceanic component of the model, in which prognostic equations are evaluated by the finite difference technique, the zonal and meridional grid size is chosen to be 1.9° and 2.2°, respectively. The computational resolution of this model is twice as high as that of earlier versions of the model commonly used for the study of climate sensitivity at GFDL. Figure 1.4 compares the maps of sea surface temperature which are obtained from two versions of the model with high and low computational resolution. According to this comparison, the distribution from the model with higher computational resolution has, generally more realistic features. Some of these features include the equatorial minimum in the eastern portion of the ocean, narrow zonal belts of large temperature gradient in middle latitudes, and more realistic deep ocean temperatures. A detailed assessment of the performance of the high resolution model is in progress.

1.5.2 Atmospheric GCM

Most of the currently used spectral models of the atmosphere employ the so-called "transform technique." In this approach, the changes of prognostic variables computed at each grid point are represented by a limited number of spherical harmonics with the higher wave components removed. This spectral truncation significantly alters the field of moisture which is constrained by saturation and has relatively small scale features. Thus, it creates many small regions of fictitious supersaturation and, accordingly, fictitious precipitation with very little horizontal coherence.

To avoid this difficulty, the Climate Dynamics Group has developed and tested a modified version of the spectral model during the last fiscal year. In this modified version, the dynamical equations are computed by use of the spectral technique, whereas the water vapor equation is evaluated by a finite difference technique. It was found that this hybrid model successfully avoids most of the fictitious "spectral rain" and yields a field of precipitation which is smooth and horizontally coherent. The improvement is particularly pronounced in low latitudes where the moisture field contains small scale characteristics.

1.5.3 Radiative Transfer Model Intercomparison Study

As described in last year's report, GFDL is a participant in the WMO-sponsored International Radiation Model Comparison. This exercise involves the use of standard "on-line" GCM radiation codes to compute IR cooling rates for approximately 30 standard temperature and mixing ratio profiles. The wide participation by modeling groups from seven other countries, as well as from major centers in the U.S. has made it possible for the first time to assess the characteristics of radiation codes used in various published climate and numerical weather prediction studies.

Radiative transfer computations used in GCM's are, of necessity, very highly simplified approximations to a complicated computational problem. There exist in the literature many approximate schemes. While these are often calibrated against other methods, a comprehensive catalogue of the behavior of various techniques does not exist. The comparison study is in part designed to remedy this situation.

GFDL submitted results from two of its models: the 9-level scheme used by Manabe and his collaborators in their climate studies, and the 40-level radiation code used in the SKYHI model of Mahlman and his co-workers. The

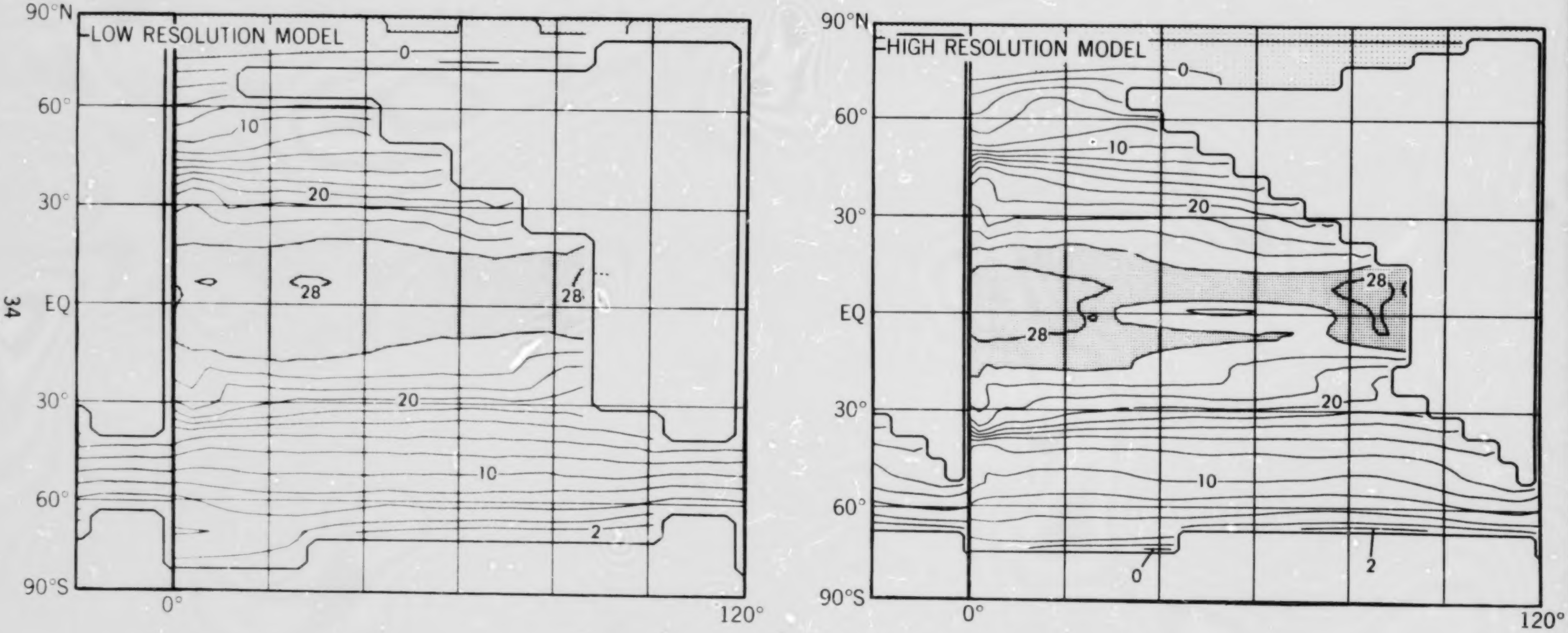
LOW RESOLUTION MODEL
90°N
60°
30°
EQ
30°
60°
90°S
0°
120°
0
10
20
28
28
28
20
10
2
HIGH RESOLUTION MODEL
90°N
60°
30°
EQ
30°
60°
90°S
0°
120°
0
10
20
28
28
20
10
0
2

Fig. 1.4--The horizontal distribution of sea surface temperature from the coupled ocean-atmosphere model with limited computational domain and an idealized geography. Left-hand side: low resolution model. Right-hand side: high-resolution model.

study has produced a great deal of data, that will take at least a year to analyze. Preliminary results are encouraging, however; the two GFDL models agree quite well with other similar models, and more importantly perhaps, with "line-by-line" calculations (see below). Those discrepancies which have been found are due to well-understood effects, such as the omission of weak bands.

The second purpose of the study is to assess the accuracy with which radiative computations can be performed when the requirement of speed is ignored, and to provide benchmarks with which the GCM algorithms can be compared. A small number of groups are therefore evaluating cooling rates using "line-by-line" models. The uncertainties inherent in these calculations stem only from uncertainties in the basic molecular physics (such as line shape), or in uncertainties in spectroscopic parameters (such as line intensities and widths).

Line-by-line calculations are computationally onerous, and GFDL has been active in this area for almost ten years. Calculations are being carried out for a sub-set of the cases used in the inter-comparison protocols. At present, cases involving pure CO_2, pure H_2O, and a mixture of both have been completed, as well as a number of runs with and without the H_2O continuum. In every case, the transmission function matrix (typically 50 x 50 levels) is accumulated at 10 cm^{-1} intervals, and stored on tape. They will be compared with those produced by other groups, carrying out similar calculations. In addition, the data will be made available for comparison with parameterized models.

1.5.4 Computation Efficiency

Major effort has been devoted to the vectorization of the computer program in the atmospheric climate model (1.5.1). As a result of this effort, the model is now running 4 times faster than on the ASC machine and almost twice as fast when compared to a year ago.

PLANS FY85

Coupled Ocean-Atmosphere Model

Continuous effort will be made to improve the general circulation model of the coupled ocean-atmosphere system. Special emphasis will be placed upon the development of a model with realistic geography and higher computational resolution.

Atmosphere-Mixed Layer Ocean Model

The atmosphere-mixed layer ocean model currently used at GFDL does not incorporate the influence of the heat exchange between the mixed layer and deeper ocean. It is planned to develop a model in which this oceanic heat flux at the bottom of the mixed layer ocean is prescribed such that a realistic distribution of sea surface temperature is maintained. Some previous sensitivity studies will be repeated by use of this revised version of the model.

General Circulation Model of the Atmosphere

One of the common shortcomings of the GFDL spectral models is that the model exaggerates the intensity of the surface westerlies in middle latitudes during winter. This shortcoming becomes more pronounced when the computational resolution of the spectral model is increased. A series of exploratory experiments will be conducted in order to overcome this difficulty.

Radiative Transfer Model Intercomparison Study

The intercomparison among the results from the line-by-line model and other simpler models will be continued.

2. MIDDLE ATMOSPHERE DYNAMICS AND CHEMISTRY

Goals

- To understand the interactive three-dimensional radiative-chemical-dynamical structure of the middle atmosphere (10-100km), and how it influences and is influenced by the regions above and below.
- To understand the dispersion and chemistry of atmospheric trace gases.
- To evaluate the sensitivity of the atmospheric system to human activities.

2.1 ATMOSPHERIC TRACER STUDIES

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H. Levy II	R. A. Plumb
J. D. Mahlman	S. C. Liu*
	*Aeronomy Laboratory/NOAA

2.1.1 Atmospheric N_2O Tracer Experiments

Final analysis has been completed on the series of experiments designed to test the sensitivity of stratospheric N_2O to various photodestruction hypotheses. The previous model analysis noted that the horizontal topography of time-mean mixing ratio surfaces should be essentially the same for "nearly conservative" trace gases.

The above result has been extended with a theoretical analysis using a quasi-analytic "2-slab" model in the meridional plane. Specifically, the theory predicts the degree of meridional "slope flattening" to be expected for a given photochemical destruction rate. The theory also predicts that the effective global average (1-D) vertical "eddy diffusion" will be different for different trace constituents. Specifically, the effective 1-D eddy diffusion coefficient is predicted to be proportional to the strength of the stratospheric diabatic circulation and to the meridional slope of the trace constituent surfaces.

A detailed comparison of the model's local temporal variability has been made against the observations given in 2.1.7. Generally, model and observations show reasonable agreement, particularly when the temporal standard deviations are divided by the local time-mean vertical gradient to yield a quantity "Δ". A simple theory has been developed which demonstrates why "Δ" statistics are so useful. Also, the theory predicts the specific manner in which "Δ" should differ among various trace constituents.

2.1.2 Reactive Nitrogen in the Troposphere

Work has continued on a set of preliminary numerical experiments designed to examine the impact of the U.S. combustion source on the global reactive nitrogen budget. This work has demonstrated the large sensitivity of the results to major uncertainties in precipitation removal of water soluble reactive nitrogen species.

In an attempt to develop a more realistic description of condensation removal, a height-dependent parameterization of the cloud filtering of rising air was devised. The scheme has been tested in the presence of both upper and lower limits of precipitation removal. The results of these tests are being analyzed along with the previous numerical experiments in preparation for publication.

2.1.3 Examination of the Classical Theory for Tropospheric Ozone

The final analysis of these numerical experiments has been completed, the model simulations have been compared in detail with observations, and a paper describing this work has been completed (w).

In general the transport simulation of tropospheric ozone has been quite successful, though there are a number of exceptions: 1) Over the ocean where the surface deposition velocity is low, there is need of photochemical destruction in the lower troposphere; 2) In the continental boundary layer where the underlying surface deposition velocity is quite high, there is need of greater vertical mixing, a seasonally dependent deposition velocity and photochemical production; 3) The transport model produces too much O_3 at northern high latitudes, though other dynamical studies suggest that the model's poleward-downward transport in the lower stratosphere is too weak rather than too strong. There may be a role for photochemical destruction in the "free troposphere" at high latitudes, although the problem may be a deficiency in high latitude tropospheric dynamics; 4) The observed summer ozone maximum in the "free troposphere" north of 30°N is not simulated by the transport model. The observed interannual variability in the seasonal behavior suggests that at least a transport controlled photochemistry (via NO_x) is needed.

2.1.4 Tropospheric Photochemistry

Diurnal photochemical calculations have been carried out for a range of NO_x concentrations in each of the four seasons at 500 mb and 45°N. The chemical steady state value of O_3 is dominated by the NO_x level and is relatively insensitive to other parameters such as temperature, solar flux and H_2O concentration. On the other hand, the chemical contribution to the O_3 net tendency is very dependent on all the variables, including NO_x. The photochemical steady state O_3 values predicted from NO_x levels which result from stratospheric injection (414) are themselves consistent with observation and much less than values predicted by the transport model. A complete understanding of tropospheric O_3 will require both modeling and observational programs which consider, at a minimum, O_3, NO_x, and H_2O. The results of this work have been combined with 2.1.3 and submitted for publication (w).

2.1.5 "Maximum Insight" Tracer Experiments

Final work has been completed on the interpretation of two idealized 3-D tracer model experiments analyzed from an isentropic coordinate perspective. The results show that the equilibrium meridional slopes of tracer isolines result from the balance between two opposing (but related) processes: the slope-steepening effect of the direct mass circulation with sinking in high latitude and rising in low latitude; the slope flattening effect of meridional tracer dispersion, essentially along isentropic surfaces (bq).

2.1.6 Development of a 2-D Transport Model

Statistics from the above 3-D "Maximum Insight" tracer experiments are being used to evaluate the feasibility of developing a self-consistent 2-D transport model. In principle, two independent tracer experiments provide all the transport coefficients and advective velocities required to test the validity of the recent "generalized diffusion tensor" 2-D transport theories.

The model coefficients have now been derived and have been tested in a 2-D model which is self-consistent in its formulation with the GFDL 3-D model.

Early results indicate that the required transport coefficents vary rapidly in space and time; they assume particularly large values near boundaries between easterly and westerly wind regimes. Also, a meridional mass transport circulation is indicated that is different from other derived meridional velocities such as the residual and diabatic circulations.

2.1.7 Observational Analysis of Long-Lived Tracers

Observational analysis has continued on the balloon samples of N_2O, CF_2Cl_2, and $CFCl_3$ from a limited network by the Aeronomy Laboratory/NOAA. Various hypotheses advanced in the work described in 2.1.1 have been evaluated. In particular, the "slope flattening hypothesis" of 2.1.1 has been shown to be compatible with the observed data. On the other hand, the prediction in 2.1.1 on the tracer-to-tracer variation of "Δ" statistics cannot yet be evaluated because of insufficient statistical significance in the data.

The observational data also suggests that N_2O may be more rapidly destroyed in the stratosphere than currently indicated by photochemical theory. Also, the analysis indicates that the meridional slope of tracer isolines in the GFDL model is somewhat flat relative to observations. This is thought to be a result of insufficient dynamical forcing of the stratosphere in the GFDL GCM used for the tracer model.

PLANS FY85

Efforts will continue on the "Combustion Nitrogen" and tropospheric ozone series, with more realistic numerical experiments planned for both. Work is to be initiated on multiple, interactive trace constituent modeling, and will be continued on analysis evaluating the feasibility of formulating a self-consistent 2-D transport model. Final work on the observational study of the climatology of long-lived trace gases will be completed.

2.2 MODELS OF THE TROPOSPHERE-STRATOSPHERE-MESOSPHERE

J. T. Bacmeister
S. B. Fels
D. G. Golder
D. S. Graves
Y. Hayashi
J. D. Mahlman
S. Miyahara
M. L. Salby
L. J. Umscheid

ACTIVITIES FY84

2.2.1 Model Improvements

In the past fiscal year, continued effort has been expended to accommodate to the CYBER 205 computer. The troposphere-stratosphere-mesosphere (SKYHI) GCM has been speeded up by an additional 35% and it has been coded to allow a capability for relatively easy changes to different horizontal resolutions.

Substantial improvements have been made in the SKYHI surface physical processes, particularly in the differential surface drag over land and ocean, and in the treatments of sea and glacier ice/snow.

2.2.2 "Low Diffusion" Medium Resolution (N18) Experiment

Final work on the previously reported SKYHI annual mean insolation experiment has been completed. This work has utilized the "transformed Eulerian" zonal momentum analysis in which the traditional eddy terms are replaced by the so-called Eliassen-Palm flux divergence (EPFD), while the paths of wave activity are closely approximated by the Eliassen-Palm flux vector.

To clarify previously reported results, a simple theory has been advanced to explain the nature of mean cell-eddy cancellation in the two types of momentum balances. In particular, the role of radiative forcing is clarified in determining the equilibrium response of zonal winds to eddy forcing. More detailed results are available in (569).

2.2.3 Analysis of Equatorial Waves in the SKYHI Model

Final work has been completed in a space-time spectral analysis of equatorial waves in the middle atmosphere as simulated by the SKYHI annual mean GCM (2.2.2).

Previous results showed the presence of three classes of Kelvin waves, including the discovery of an "ultra fast" wave (phase speed ~ 130 m sec^{-1}.) Also, the importance of gravity waves in the mesospheric momentum budget was identified. Recent analysis points out the presence of "saturated" waves in the mesosphere with effectively constant amplitude in height. A time-height cross section clearly reveals a vertical group propagation of Kelvin waves. Also, the presence of a 16-day westward moving planetary wave has been identified. This wave shows strong correspondence with observation and theories. Details of this work are available in (m).

2.2.4 Generation and Dispersion of Equatorial Disturbances

Work has been completed on a series of calculations designed to clarify the mechanisms producing the middle atmosphere tropical disturbances observed by satellite (577) and modeled in SKYHI (2.2.3). Linearized, 3-D primitive equations in a sphere are used to determine the response to unsteady local heating in the tropics.

The transient wave response to this forcing takes the form of a Hough space-time spectrum, representing the dispersion of wavepackets out of the source region. This dispersion is composed of two classes of disturbances corresponding to: (1) Large values of Lamb's parameter, with disturbance trapped laterally about the equator, but propagating vertically; (2) Small values of Lamb's parameter, with disturbances composed of planetary normal modes which propagate out of the tropics, but which are trapped vertically.

For localized heating near the equator, the dominant response is provided by a spectrum of Kelvin waves. Differential absorption of slower Kelvin waves relative to faster ones may explain the shift to higher frequencies with increasing altitude as recently discovered in satellite observations (577) and in the GFDL SKYHI model (2.2.3).

2.2.5 Medium Resolution (N18) Seasonal Cycle Experiment

Analysis of this model experiment has been terminated because the SKYHI simulation has been markedly improved in a higher resolution (N30) experiment (see 2.2.6). Details of this N18 experiment are published in (590).

2.2.6 Higher Resolution (N30) Seasonal Cycle Experiment

A higher resolution (N30), seasonal cycle version of the SKYHI GCM has been integrated for more than 16 months. Compared to the previous N18 model (2.2.5), a number of marked improvements (but not disappearance) of previous simulation deficiencies have been achieved.

In the troposphere, the subtropical jets have moved poleward nearer their observed positions. The tropical upper tropospheric winter westerlies have reduced considerably, as has the model tendency to simulate too strong surface easterlies. The magnitude of maximum vertical component of Eliasen-Palm flux is now essentially the same as observed, while the position of the maximum is much closer to its observed location near 60°N.

In the N30 model stratosphere, the winter cold polar bias problem has been all but eliminated above 50 km. It has been reduced considerably in the lower and middle stratosphere, particularly in late winter. The model now exhibits large amplitude winter planetary waves and attendant sudden stratospheric warmings. Also, the easterly phase of the equatorial semi-annual oscillation is closer to that of observation.

A remaining problem in the N30 model is the tendency for greater than observed polar cooling in early winter. Also, the model still shows no tendency to simulate the quasi-biennial oscillation of the equatorial stratosphere.

2.2.7 Evaluation of Satellite Sampling of the Middle Atmosphere

A research project is underway to provide some estimates on the types of errors to be expected in satellite remote sampling of the middle atmosphere. The approach chosen is to use the new SKYHI GCM N30 seasonal cycle experiment (2.2.6) as a sample data set in which all variables are known "perfectly." In this case, "perfect" corresponds to the horizontal resolution of the model (50 zonal wavenumbers). This model is then sampled asynoptically in a way similar to that in which nadir-viewing polar orbiting satellites sample the actual atmosphere (zonal wavenumbers 1-6).

Provisional analysis indicates that the sampled temperature field analysis is usually within 2-4°C of the actual local model temperature. However, these relatively modest errors produce eddy momentum flux convergences that are as much as 25% in error.

2.2.8 Effects of Internal Gravity Waves on Planetary Waves

Work has been completed on the first phase of an investigation of effects of internal gravity waves on planetary waves in the middle atmosphere. A quasi-geostrophic numerical model on a mid-latitude beta plane is used to show that drag forces due to gravity waves act to suppress planetary waves in a manner similar to that of Rayleigh friction. Detailed results are available in (r).

New work has begun to analyze the effects of gravity waves on planetary waves in the N30 (later N90) SKYHI GCM (2.2.6). Preliminary results indicate that the GCM gravity waves are acting to damp middle atmosphere planetary waves in analogous fashion to that identified in the above study.

2.2.9 Non-Linear Gravity Wave - Critical Layer Interaction

Gravity waves on spatial scales smaller than currently resolved by GCM's have been proposed as significant sources of turbulent dissipation and momentum deposition in the middle atmosphere. New work is underway on the propagation and breakdown of such smaller-scale gravity waves.

Work completed to date includes development of a 2-D non-linear, non-hydrostatic numerical gravity wave model. Studies have begun on the breakdown of gravity waves at a local critical level. Early emphasis has been on determining the impact of model resolution, Richardson number, and wave amplitude on the simulated behavior.

2.2.10 Effects of Mean Damping on Wave-Mean Flow Interaction

A theoretical study has been completed on the effects of mean damping on wave-mean flow interactions in the middle atmosphere. A condition is derived for which the Eliassen-Palm flux convergence balances the residual mean circulation induced by eddies in the presence of mean damping. A simple analytical model shows that this balance holds for stratospheric planetary waves when the Rayleigh friction coefficient is one order of magnitude smaller than the Newtonian cooling coefficient. The implied balances are consistent with those of the SKYHI model (2.2.2 and ref.569). For details, see (ax,ay).

PLANS FY85

Improvements to the SKYHI GCM will be made in the areas of physical parameterizations, radiative transfer, computational efficiency, and an expanded vertical resolution. Analysis will be underway on the dynamical behavior of the N30 annual cycle experiment, including sudden warming diagnosis, impact of gravity waves on planetary waves, and identification of satellite sampling errors. Early investigation of a high resolution (N90) SKYHI experiment is underway. Work will continue on the effect of gravity waves in middle atmosphere dynamics.

2.3 PHYSICAL PROCESSES IN THE MIDDLE ATMOSPHERE

S. B. Fels
M. D. Schwarzkopf
J. D. Mahlman

S. C. Liu*

*Aeronomy Laboratory/NOAA

2.3.1 Radiative Damping in the Mesosphere

Calculation of radiative damping times for short-vertical scale waves in the mesosphere have been completed, and the results published (o). The dependence on vertical wavelength is much smaller than that used by some other investigators. This suggests that radiative damping of mesospheric gravity waves may be of minor importance. A parameterization of the calculated damping rates has been also derived which make their incorporation in simpler dynamical models relatively straightforward.

2.3.2 Seasonal March of Radiative-Dynamical Temperatures

The role of the transient effects due to seasonally varying radiative forcing is being investigated by use of a simple zonal model. In particular, the effect of the inertial term in the zonal wind equation is being examined (the "flywheel" effect). Like the time marched radiative and radiative-photochemical experiments carried out previously, these results lead to further understanding of the behavior of the SKYHI GCM and of the stratosphere itself.

2.3.3 Ozone Photochemistry

The collaborative effort with NOAA Aeronomy Laboratory scientists has continued with an emphasis toward developing an ozone photochemical model which is compatible with the SKYHI GCM (2.2). During the past year work on this project has slowed, largely due to conflicting priorities among the various collaborative researchers.

PLANS FY85

Plans will continue on the interaction of radiation and ozone photochemistry. The chemical codes will be developed further toward the goal of incorporating a self-consistent ozone field in the SKYHI GCM.

3. EXPERIMENTAL PREDICTION

GOALS

* To develop more accurate and efficient atmospheric and oceanic GCM's suitable for monthly and seasonal forecasts.

* To identify important external forcing mechanisms for the forecast range of several weeks to several months, as well as accurately specify initial states of the atmosphere, oceans, soil and snow-ice.

* To investigate the influence of additional internal processes such as orographic effect, cloud-radiation interaction and cumulus convection upon atmospheric variability on the seasonal time scale.

* To study the mechanisms of various atmospheric phenomena such as blocking, orographic cyclogenesis, equatorial ocean-atmosphere interaction, tropical circulations, and teleconnections.

3.1 LONG-RANGE FORECASTING

K. Miyakoda	R. T. Pierrehumbert
J. Sirutis	W. F. Stern
J. J. Ploshay	Y. Lu
D. Reynolds	B. Wyman

ACTIVITIES FY84

3.1.1 Monthly Forecasts

The "1980-version GCM" (i.e., N48L9-E) has been frozen and is being applied to eight January cases of monthly prediction for the years 1977-83. Each stochastic forecast consists of an average over three individual forecasts, starting from slightly different initial conditions. Besides these basic experiments, two additional forecasts are being made for each case. One is a forecast with an advanced cumulus parameterization (i.e, N48L9-F) and the other is a forecast with enhanced terrain from the European Centre for Medium Range Weather Forecasting (i.e., N48L9-M). The new experiments confirm earlier indications that monthly forecasts of ten-day average weather patterns by numerical means often exhibit significant skill.

3.1.2 Effect of Sea Surface Temperature Anomaly

The effects of sea surface temperature (SST) on the monthly forecasts are being investigated in collaboration with D. Reynolds of the Climate Analysis Center. The SST anomaly distributions for the eight January cases referred to above have been produced by Reynolds; one of the cases includes the exceptionally strong El Niño event of 1983. Simulations including forcing by the SST anomalies are now in preparation.

PLANS FY85

Monthly forecasts of the remaining January cases will be completed. The investigation of sea surface temperature anomaly effects will be continued.

3.2 MODEL IMPROVEMENT

C. T. Gordon	R. T. Pierrehumbert	F. Mesinger	K. Miyakoda
J. Sirutis	W. F. Stern	R. F. Strickler	R. K. White
B. Wyman	G. Vandenberghe	B. C. Carissimo	P. L. Baker

ACTIVITIES FY84

3.2.1 Various Versions of Subgrid-Scale (SGS) Processes

Work on the performance of atmospheric GCM's with three different treatments of SGS parameterization (A, E, and F, in order of increasing complexity) has been continued. In addition, a fourth version (FM) with enhanced mountains has been added. Each version has been integrated for 30 days for each of six cases. These experiments have revealed that the effects of SGS parameterization over the monthly time scale are substantial, improving the forecast skills and the simulation of blocking formation and maintenance. Overall, the most elaborate model 'FM' seems to be best for this time scale. However, further investigation is needed.

Figure (3.1) shows the geographical distributions of forecast errors of 500 mb geopotential height in four prediction models for Day 10-30; each map is derived from simulations of four different Januaries. Figure 3.1 shows the root-mean-square of the errors of the four individual forecasts, whereas Figure 3.2 shows the mean of the errors of the forecasts. The latter are the systematic errors often called "climatic drifts." It is interesting to note that the errors in Figure 3.1 are very similar to those in Figure 3.2 within the respective models, implying that the forecast errors are mostly due to the climatic drifts.

3.2.2 Cloud-Radiation Interaction

Tests of a cloud prediction scheme have been partially completed. According to this scheme, cloud amount varies over a prescribed range of critical relative humidity. The latter is GCM- and latitude dependent, and optionally, sigma-dependent. Also, NIMBUS 7 radiative flux data is being processed to generate additional monthly mean effective cloud amount fields.

3.2.3 Orographic Effects

Investigations of the effects of mountains on the atmosphere have continued, and a number of projects have come to fruition. In the long term this work is intended, in part, to help improve the representation of mountains in numerical models. The first group of projects is aimed at elucidating the circumstances under which a mountain causes substantial diversion of the oncoming flow. Linear results addressing this problem have appeared in print (610). Additionally, an extensive numerical study in pursuit of the ideas introduced in (e) has been carried out; a manuscript describing the results is currently undergoing internal review. This study treated the transient ageostrophic problem and produced general quantitative results on the range of atmospheric conditions under which flow is diverted around a mountain of given dimensions. Moreover, a number of long-standing issues concerning far-upstream influence in continuously stratified flow over an obstacle were resolved.

The second group of projects concerns the formation of cyclones in the lee of mountain ranges. A new theory describing the modification of baroclinic instability by steep orography was completed and submitted for publication (ag). Also, a review article on observational and theoretical aspects of cyclogenesis in the lee of the Alps and the Rocky Mountains was completed, and will be submitted for publication shortly. Work continues on analysis of the ALPEX data, but finalization of this work awaits the availability of the Level IIb data set.

3.2.4 High Resolution Spectral Model

The next generation spectral model, (63 wave resolution and 36 levels, denoted R63L36) is being developed. The model will include an envelope orography and lateral subgrid-scale turbulence parameterization. Three

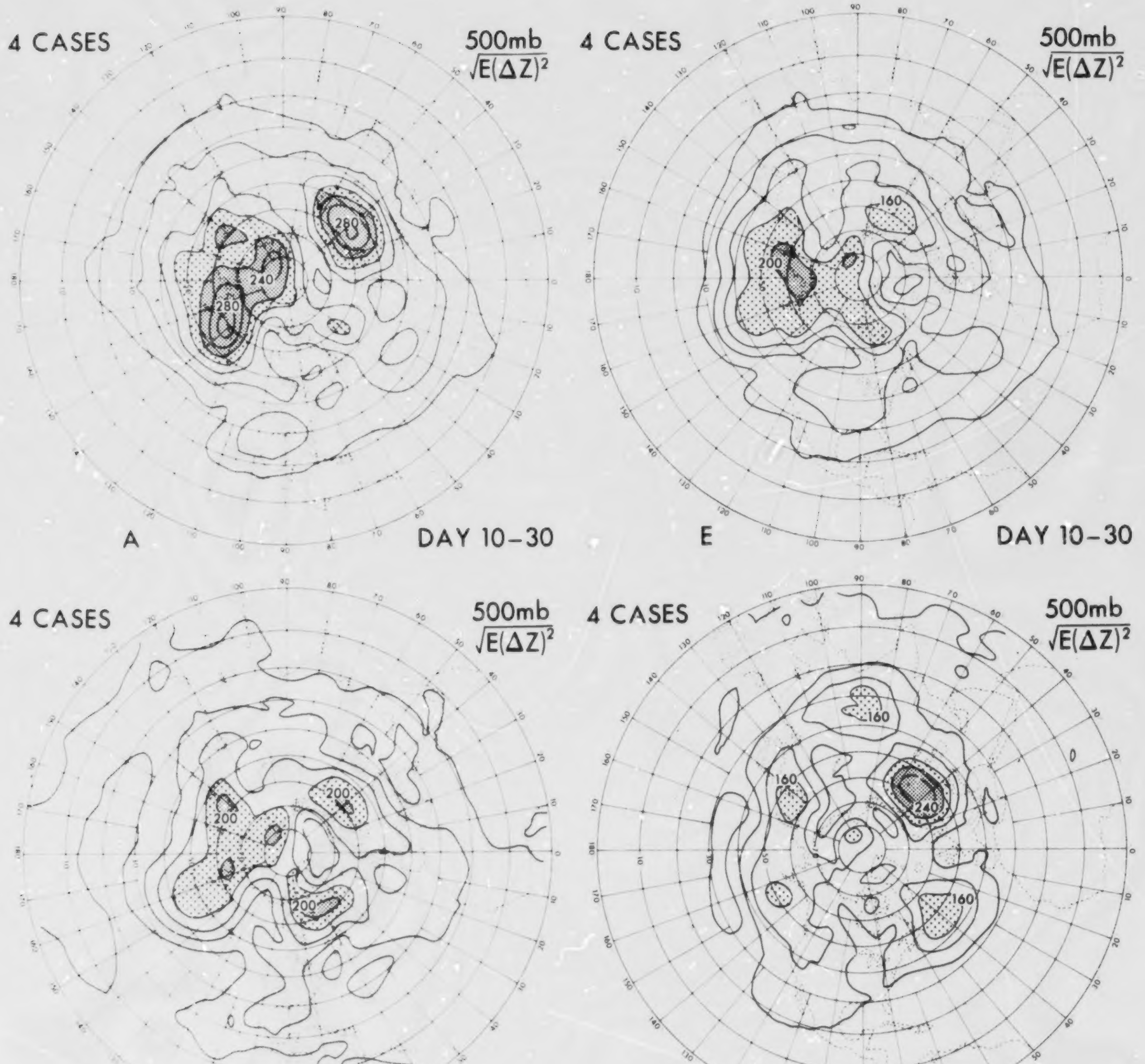
4 CASES
500mb
$\sqrt{E(\Delta Z)^2}$
280
240
280
A
DAY 10-30
4 CASES
500mb
$\sqrt{E(\Delta Z)^2}$
160
200
E
DAY 10-30
4 CASES
500mb
$\sqrt{E(\Delta Z)^2}$
200
200
200
F
DAY 10-30
4 CASES
500mb
$\sqrt{E(\Delta Z)^2}$
160
160
240
160
FM
DAY 10-30

Fig. 3.1--The root-mean-square error of geopotential height at 500 mb, $\sqrt{E(\overline{\Delta Z})^2}$, for Day 10-30 in various models, A, E, F and M. $\Delta\overline{Z}$ is the forecast error averaged over Day 10-30, which is equal to $Z_{prd} - Z_{obs}$, where Z_{prd} and Z_{obs} are the predicted and the observed height, respectively. $E(\Delta Z)^2$ is the ensemble mean of $(\Delta Z)^2$ over four cases of Januaries and March. The contour interval is 40 meters.

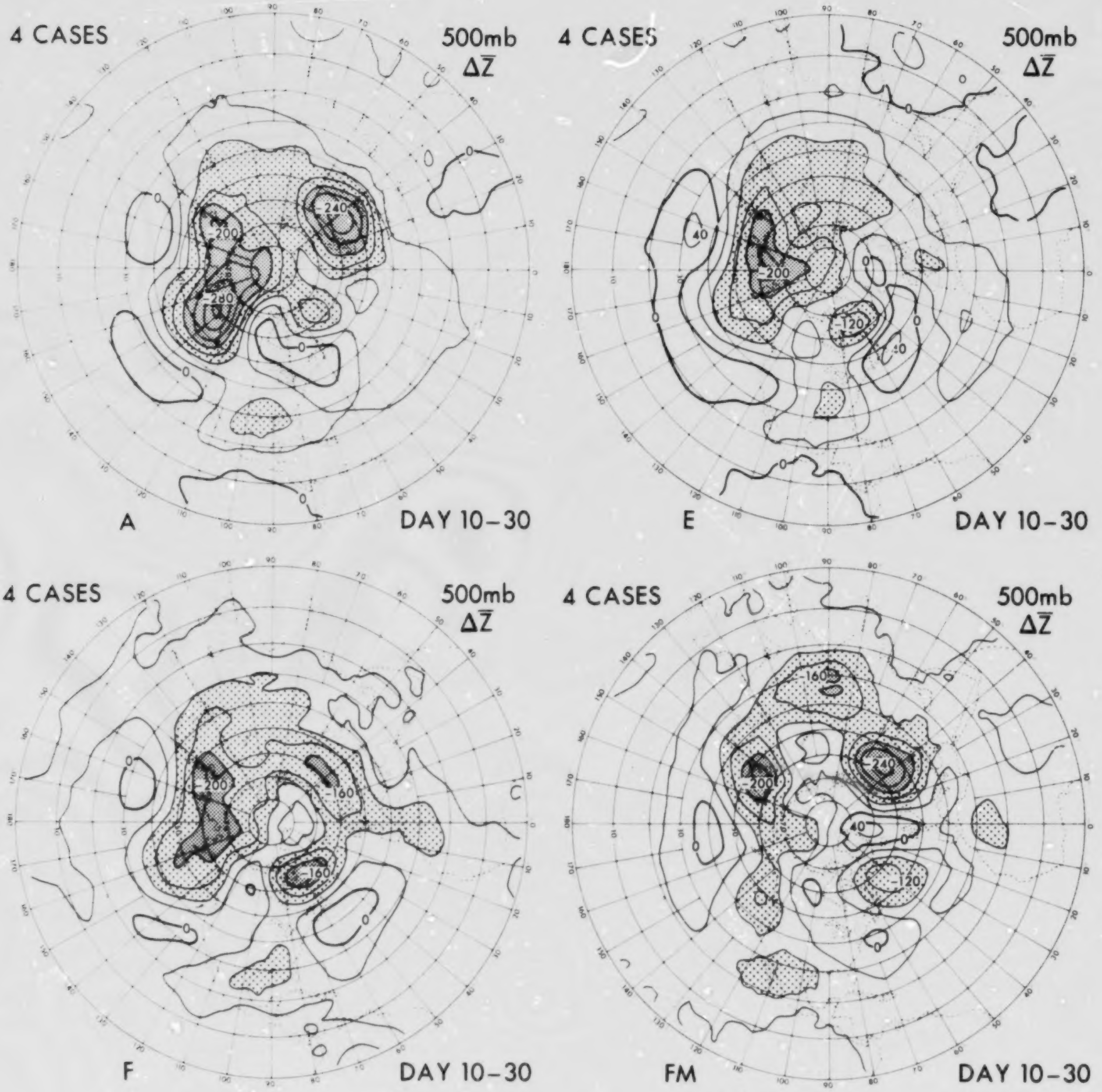
4 CASES
500mb
ΔZ̄
-240
-200
-280
0
A
DAY 10-30
4 CASES
500mb
ΔZ̄
40
-200
-120
0
E
DAY 10-30
4 CASES
500mb
ΔZ̄
-200
-160
-160
0
F
DAY 10-30
4 CASES
500mb
ΔZ̄
-160
-200
-240
40
-120
FM
DAY 10-30

Fig. 3.2--The arithmetic mean of 500 mb geopotential height error, $E(\overline{\Delta Z})$, in various models, where $(\overline{\ \ })$ is the time mean over the twenty days. The contour interval is 40 meters.

monthly forecasts have been run for an intermediate resolution (R42L9-E) model and comparisons with the standard R30L9-E results are encouraging. There is an indication of more energetic transient features in the R42 model for the medium to long range forecast. The extension to R63 is currently taking place.

3.2.5 HIBU Model

A higher-resolution global version of the HIBU advanced gridpoint model with E2 physics has been completed. The model has 3 degree spacing in latitude and longitude between neighboring temperature points on a staggered mesh (1.5 degrees between velocity and temperature points). Optimization efforts have brought the running time down from about 80 minutes per forecast day to about 40 minutes per forecast day. Preliminary three-day forecasts have shown the skill of the model to be excellent.

PLANS FY85

The sensitivity of one month forecasts to model-predicted versus specified monthly mean cloud amount fields will be investigated. Improvement of computational efficiency for the R63 model will be started, adapting the transposed matrix method of NMC. The results on orographic effects will be extended to less idealized situations.

3.3 DYNAMICS OF PLANETARY WAVES AND BLOCKING

R. T. Pierrehumbert K. Miyakoda
A. Navarra

ACTIVITIES FY84

3.3.1 Theoretical Studies of Transient Eddy Fluxes and Blocking

An earlier study on the forcing of high amplitude anomalies by vorticity sources has appeared in print (574). This study indicated the importance of the relation between the large scale flow pattern and the synoptic scale baroclinic transients growing on that pattern. A new theory treating the distribution of cyclogenesis in relation to large-scale flow patterns was completed and has been accepted for publication (ag). This theory is based on a WKB asymptotic analysis of the baroclinic instability of a zonally varying flow; while it was carried out explicitly only for a very idealized flow, the techniques developed can be extended to more realistic situations.

3.3.2 Stationary Linear Model and Time-Dependent Nonlinear Model

This is a continuation of the studies of "anomaly models," reported in FY82. Now the stationary linear primitive equation system, which has a comparable size to a spectral R15L9 GCM, can be solved with respect to perturbations around a three-dimensional basic flow. This capability is essential for the construction of a successful anomaly model, and it is achieved only by inverting an extremely large matrix with the Krylov method. This work permits the extension of earlier work on forced planetary waves to the case in which the basic state is not zonally symmetric.

PLANS FY85

The time-dependent nonlinear anomaly model will be tested.

3.4 FOUR-DIMENSIONAL DATA ASSIMILATION

N.-C. Lau	K. Puri
J. J. Ploshay	W. F. Stern
K. Miyakoda	R. K. White

3.4.1 FGGE Data Studies

The books of daily weather maps for FGGE Level IIIb data produced at GFDL (Parts I, II, III and IV) have been published, and another containing monthly mean statistics is in press. The first national workshop on FGGE was held at Woods Hole, MA, in July, 1984. The impression from this workshop of the GFDL FGGE Level IIIb analysis is that the product is useful in the sense that there are no serious flaws, but deficient in terms of the noisiness in the analysis and the shallowness of cyclones. It appears in any event that continuous data insertion in a four-dimensional data assimilation has proved competitive with the conventional intermittent data assimilation method.

3.4.2 Improvement of Four-Dimensional Analysis

Areas in which the FGGE 4-D system could be improved have been identified to include (1) a reduction in the amount of fast modes generated during assimilation; (2) increased acceptance of surface pressure data; and (3) more consistency between observation density, optimum interpolation (OI) and the model resolution. Several experimental assimilation systems were developed and tested. It has been shown that a selective linear normal mode initialization could be applied to the data increments at each time step to greatly reduce the amount of fast modes generated while retaining the meteorologically significant information. In addition, the incorporation of a geostrophic correction technique and enlarging the OI influence region have improved the acceptance of mass data. Plans include redoing much of the Special Observing Period II (SOP2) with the improved assimilation system. It would also seem worthwhile to continue to refine the data analysis system as there are indications that these analyses often yield better long-range forecasts.

3.4.3 Hadley and Walker Circulation at the Indonesian Archipelago

The pronounced tropical vertical velocity located at the Indonesian area has been studied using FGGE data. It was revealed that this vertical velocity is mostly due to the condensational heating related to cumulus convection, that the upward velocity consists of gravity waves, and that in the continuous data assimilation process the Hadley circulation feature can be produced by applying the nonlinear normal mode initialization only to the high frequency modes (greater than $(6\ \text{hr})^{-1}$) or by using the diabatic nonlinear normal mode method. For calculating the Walker circulation, it is necessary to take into account the sea surface temperature anomaly for the boundary forcings.

PLANS FY85

The improved data assimilation system will be applied to the SOP2 data of FGGE, simultaneously calculating the heat sources and sinks.

3.5 AIR SEA COUPLING FOR UPPER OCEAN FORECASTS

A. Rosati K. Miyakoda
J. Sirutis C. T. Gordon

ACTIVITIES FY84

The 3-dimensional ocean GCM, including the turbulence closure theory of level 2.5 and nonlinear lateral viscosity has been completed and tested. The merit of this model is that the oceanic and atmospheric GCM's, if coupled, have exactly the same formulations and constants for the subgrid-scale parameters. Presently, the horizontal grid resolution is extremely poor (5° in latitudinal and longitudinal directions). The atmospheric forcings for the El Niño of 1982-83 are being applied to this model.

PLANS FY85

The lateral resolution of the ocean GCM will be increased.

3.6 COOPERATION WITH NATIONAL METEOROLOGICAL CENTER (NMC) AND AUSTRALIAN METEOROLOGICAL RESEARCH CENTRE (ANMRC)

W. F. Stern J. Sela* K. Puri**
J. Sirutis B. McAvaney** * NMC
K. Miyakoda F. Mesinger ** ANMRC

ACTIVITIES FY84

3.6.1 Cooperation with NMC

In an effort to extend and improve NMC's forecast capability, a collaboration has been established between GFDL and NMC with the major objective being the implementation of GFDL physics in the NMC spectral model. At this time, both the A2 and E2 physics packages have been incorporated and have produced reasonable short range forecasts. These physics coupled with an R40L18 model are currently undergoing testing at NMC. Future plans are to continue tests with the E2 version and to incorporate the E4 physics in the NMC model. Through this cooperation, it is also expected that the E physics will undergo an extensive evaluation via the large number of forecasts that NMC will carry out, especially if it is involved operationally. In addition, having a version of the NMC model at GFDL will allow incorporation of many of the NMC efficiency techniques.

3.6.2 Cooperation with ANMRC

Assistance was provided to B. McAvaney from ANMRC to convert the ANMRC spectral model to run on the Cyber 205. The ANMRC model was converted, successfully run and partly vectorized. In addition, a forecast using the ANMRC hemispheric spectral model from one of their FGGE SOP1 analyses was provided for comparison.

PLANS FY85

In the NMC-GFDL cooperation, the turbulent closure of level 2.5 (called the E4-Physics) will be included.

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4. OCEANIC CIRCULATION

GOALS

- To study the large-scale response of the ocean to atmospheric forcing over a range of time scales from a few weeks to decades.
- To perform oceanic observational studies by systematically processing the large data base available for the density structure and the fields of various tracers.
- To develop detailed, three-dimensional models of the World Ocean and its regional components and interpret these in terms of a coherent hydrodynamical framework.
- To develop a capability to predict the large-scale behavior of the World Ocean in response to changing atmospheric conditions.
- To identify practical applications of oceanic models to man's marine activities.
- To formulate and to test against observations a coastal ocean model which has a detailed surface layer and bottom boundary layer.

4.1 OCEANIC RESPONSE STUDIES

R. Gardiner-Garden	A. D. Seigel
R. Greatbatch	T. Yamagata
R. C. Pacanowski	S. G. H. Philander

ACTIVITIES FY84

4.1.1 Simulation of the Seasonal Cycle of the Tropical Atlantic

The high resolution three-dimensional model of the tropical Atlantic Ocean was refined so as to simulate not only the variability of the oceanic currents but also that of the sea surface temperature, by far the most complex of the oceanic variables. To accomplish this, the number of vertical levels in the model was increased (to 27, so that grid-spacing is 10m near the ocean surface) and the heat flux boundary condition at the surface was improved. For example, if the ocean is forced with monthly mean winds then it is necessary to take evaporation associated with high frequency wind fluctuations into account by specifying background wind noise. Preliminary information is available in (ad). Repetition of the simulation, in which simplifying assumptions are made, have been started. Thus the suppression of nonlinearities, and of the meridional component of the wind, will permit an assessment of the importance of these factors.

4.1.2 Simulation of 1982-1983 El Niño

The primitive equation tropical ocean model has been forced with observed winds (obtained from NMC) to simulate the 1982-1983 El Niño event (See Figure 4.1). The model reproduces the few available measurements - sea level at several islands, time-series of currents on the equator at 110°W and 160°W, and the evolution of the sea surface temperature pattern - surprisingly well. From the model it is clear that the disappearance of the Equatorial Undercurrent was associated with a disappearance of the zonal density gradient that maintains it. This happened when the easterly winds became westerly. Another novel result is the intensification of the eastward surface current between approximately 5°N and 10°N. This current was responsible for a large part of the eastward transfer of warm water. Analyses of these results are continuing.

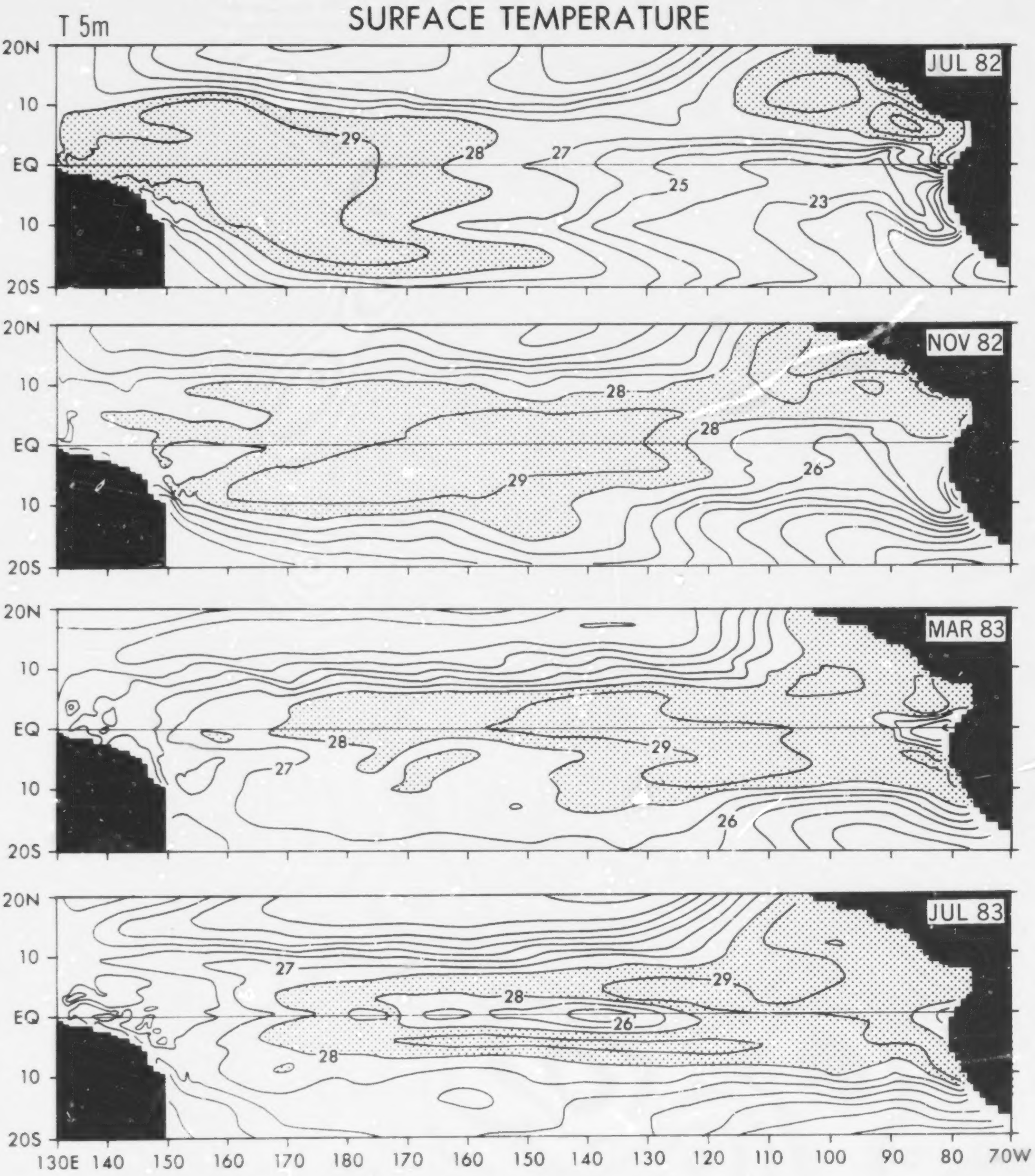
4.1.3 Dynamics of Tropical Oceans

A study of the nonlinear adjustment of a shallow-water tropical ocean to the sudden onset of zonal winds reveals that solitary waves, which persist for a considerable time, can be generated. These solitons appear in pairs and can initiate meanders of the equatorial currents.

PLANS FY85

Detailed comparisons between measurements of the seasonal cycle in the tropical Atlantic and model simulations will be undertaken to determine the deficiencies of the model.

The mass and heat budgets of the seasonal cycles of the tropical Atlantic and Pacific Oceans, and of the 1982-1983 El Niño event, will be studied to


T 5m
SURFACE TEMPERATURE
JUL 82
NOV 82
MAR 83
JUL 83
29
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80
70W

Figure 4.1 -- Evolution of the sea surface temperatures in a model simulation of the 1982-83 El Niño.

determine how heat and mass transports in the ocean change seasonally and interannually.

Studies of interactions between the tropical ocean and atmosphere, to better understand phenomena such as the Southern Oscillation, will continue by using a hierarchy of models.

4.2 MARINE GEOCHEMISTRY

F. Bryan
*S. Hellerman
M. Jackson
*E. Romer
*R. Rotter
M. Kawase
*R. Key
D. Papademetriou
J. L. Sarmiento
J. R. Toggweiler

* Princeton University

ACTIVITIES FY84

The major emphasis of the geochemistry group during the last year has been the development of a model of carbon cycling within the oceans. A consideration of the problems involved led to the development of a simple box model which showed that atmospheric carbon dioxide is very sensitive to the level of preformed nutrients in high latitude deep water formation regions (bj). Preformed nutrients are determined by the rate of supply by circulation relative to uptake by organisms. A time-dependent version of the model has recently been completed that shows that the response time of the atmospheric carbon dioxide to a change in ocean circulation has a time scale of the order of 200 years. This finding is of great interest both as a possible explanation of the low carbon dioxide levels of the last ice age, and as a possible feedback mechanism on the fossil fuel carbon dioxide increase.

Work with tritium measurements for the period prior to the Transient Tracers in the Oceans Project (TTO) has been completed with the publication of a paper on a three-dimensional simulation of the tritium distribution (566) and a box model study of thermocline ventilation (561) which shows that seasonal convection and isopycnal mixing dominate over Ekman pumping.

A study of the parameter sensitivity of primitive equation ocean circulation models shows that models with equatorially symmetric forcing appear to be unstable to perturbations, preferring an asymmetric pole to pole meridional overturning. The development of a new North Atlantic circulation model has been initiated which will be used for a WOCE Numerical Experimentation Group model intercomparison study, and for the carbon cycle model development project.

The radium-228 laboratory continues to measure samples collected during TTO. Two papers based on work in the North Atlantic and Amazon River have been completed and accepted for publication (bm; bn).

PLANS FY85

Work on the global carbon cycle will be extended by combining the existing model with a detailed three-dimensional model of the ocean circulation.

The model of the North Atlantic circulation for WOCE intercomparison studies will be adapted for transient tracer studies. The construction and analysis of TTO data sets will continue.

4.3 WORLD OCEAN STUDIES

K. Bryan
N. Bogue
R. Wajsowicz
M. D. Cox
K. Dixon

ACTIVITIES FY84

Global models to be coupled with the atmosphere were extensively tested to find the minimum horizontal resolution necessary for a good simulation of the thermohaline circulation and poleward heat transport by ocean currents. Low resolution models are found to systematically underpredict the intensity of bottom water formation.

Extensive studies of the role of mesoscale eddies in the general circulation of the ocean have been carried out in the simplified context of quasi-geostrophic models. The CCCO/JSC Tokyo study conference of the World Climate Program strongly recommended the study of mesoscale eddies in more general models including thermodynamic processes. The new computer system at GFDL has allowed extensive computations with such a model for a basin extending from the equator to a latitude of 65°, and extending 60° in longitude in the zonal direction. The eddy resolving solution was compared in detail with a lower resolution model (595) with identical boundary conditions, but without eddies. One striking effect of the eddies is to cause a rapid homogenization of properties on density surfaces. Tongues of tracer and potential vorticity, appearing on density surfaces in the subtropical gyre of the non eddy-resolving model, disappear in the eddy resolving model. The mixing process is much more rapid than has been suggested in previous studies.

Another interesting finding involves the poleward heat transport by mesoscale eddies (Figure 4.2). The total heat transport is nearly the same in the eddy resolving and non eddy-resolving cases. The poleward heat transport by eddies is almost exactly cancelled by a thermally indirect meridional cell transporting heat against the prevailing thermal gradient. The analogy with a similar effect in the middle atmosphere is being investigated.

PLANS FY85

The extensive statistics derived from the eddy resolving model will be analyzed. Additional runs will be carried out to determine the downward transport of tracers in the presence of eddies.

The resolution of the global general circulation model will be improved, and tests carried out to determine the rate of water mass formation.

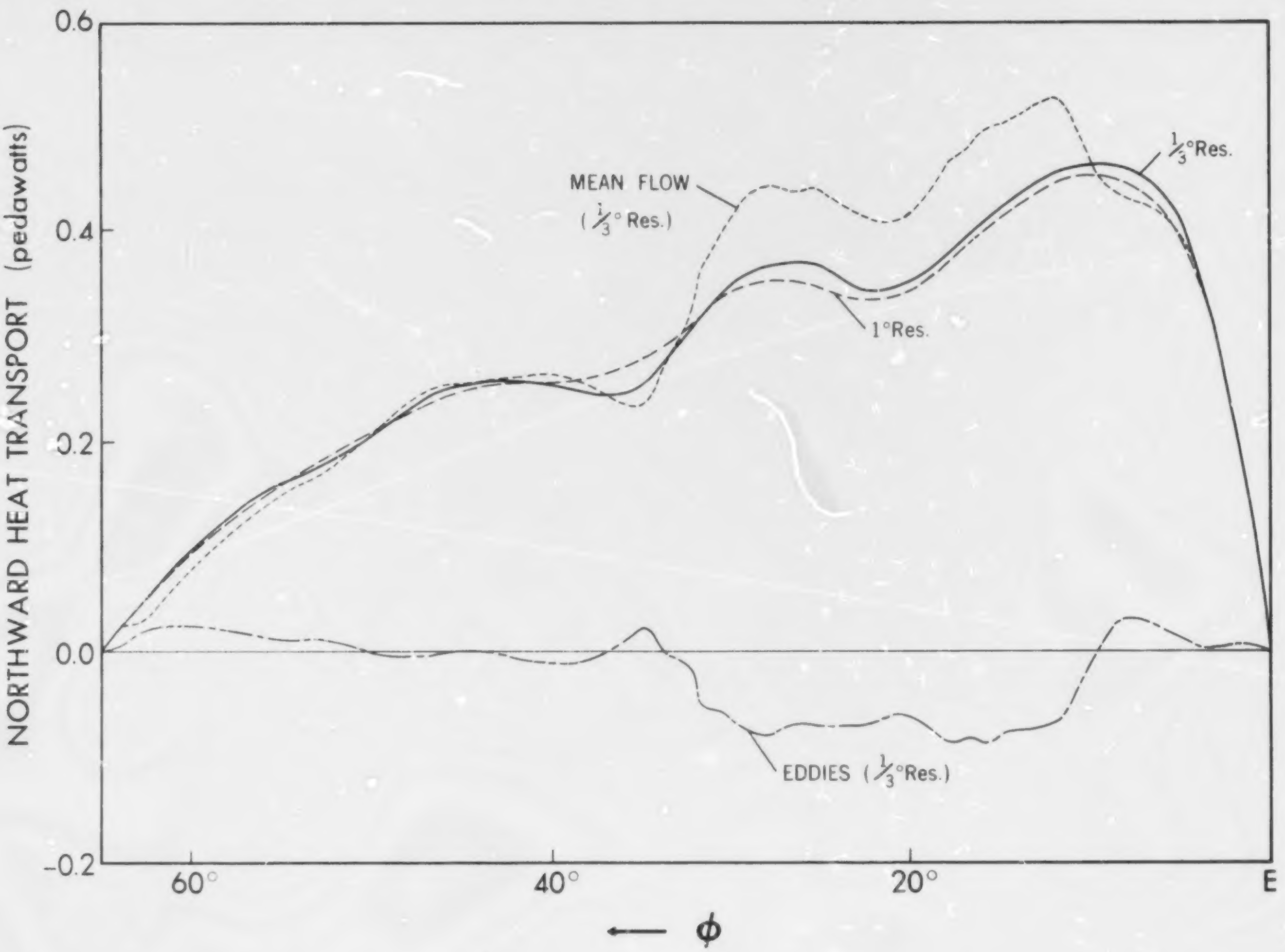

Figure 4.2 -- Poleward heat transport in a three dimensional model of the ocean. The results of a non-eddy resolving model (1° x 1° latitude and longitude resolution) are compared to an eddy resolving model with 1/3° spacing. Mesoscale eddies transport heat equatorward in the subtropical gyre, but note that this effect is almost exactly cancelled by increased poleward transport by time-averaged flow.

4.4 OCEAN MODEL DEVELOPMENT

ACTIVITIES FY84

Work has been carried out to convert the coupled ocean-ice dynamics model to the CYBER-205, and modify the model for incorporation in the joint ocean/atmosphere model.

An isopycnal model of a wind-driven ocean circulation has been developed and tested against analytic solutions for a variety of cases. The model is able to deal with the outcropping of isopycnal surfaces in a realistic manner.

An analysis of the propagation of Rossby waves in a finite difference model has been carried out which reveals the errors in phase speed and group velocity which take place in the limit of marginal resolution.

PLANS FY85

Thermal driving will be introduced in the isopycnal model. Transient response will be attempted in the isopycnal coordinate system. The ocean circulation program will be standardized and documented.

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5. PLANETARY CIRCULATION

GOALS

- To discover and understand the fundamental processes controlling the circulations of the atmospheres and oceans of the planets.
- To develop numerical models capable of simulating the major features of other planetary atmospheres.

5.1 PLANETARY ATMOSPHERES: JUPITER, EARTH, SATURN, URANUS, SUN

G. P. Williams R. J. Wilson

ACTIVITIES FY84

The extensive computation and analysis were completed for the multiple experiments made to examine the response of different versions of the GFDL spectral GCM to changes in the external parameters (rotation rate, obliquity, diurnal period). Model variations are characterized by the presence or absence of moisture, longitudinal variation and surface exchange. The implications of these solutions for the planets has been discussed in (497). Essentially, it appears as if the outer planets resemble larger, faster spinning, more oblique versions of Earth, and Venus resembles a slowly rotating Earth. If the analogy holds for Uranus - to be subject to Voyager encounter in 1986 - then easterly winds should be observed in the summer hemisphere. Although a wide variety of circulations has been obtained, our analysis indicates that standard processes are at work in all of them.

Study of the solitary vortices that occur at the Intermediate-Geostrophic (IG) scales of planetary motion has suggested that Jupiter's Great Red Spot (GRS) and Large Ovals are related to such phenomena. Both the genesis and longevity of the GRS and Ovals have been simulated using the shallow water model. The birth of the GRS was duplicated by growing a single IG vortex from perturbations to a weakly barotropically unstable zonal current. Model improvements allow us to create and maintain IG vortices for virtually indefinite periods. The various properties of IG vortices have been explored over a wide range of conditions. The fact that barotropic instability takes the form of solitary vortices, not of waves, when scales exceed the radius of deformation may be relevant to the early stages of hurricane formation.

PLANS FY85

Completion of the manuscripts documenting the study of multiple global circulations and their publication should bring this lengthy project to completion.

Model development will continue for the atmospheric circulations of Jupiter and Venus.

The nature of coherent vortices in 3-dimensional models will be examined to develop more realistic models of the Great Red Spot.

5.2 VENUS ATMOSPHERIC TIDES

D. Crisp J. Schofield*
S. B. Fels
* Department of Atmospheric Physics, Oxford University

ACTIVITIES FY84

The horizontal and vertical structure of propagating tides are both sensitive to the form of the zonal mean wind $U(\theta,z)$. It is, therefore, possible to use the observed behavior of the semidiurnal tide in the Venus mesosphere to obtain information about U.

A detailed tidal model has been used to predict the semidiurnal tidal component of the temperature for a large number of different zonal wind profiles. These temperatures were then used to generate synthetic radiances for the channels used by the Venus Orbiter Infrared Radiometer, and the results compared with observations. By means of this technique, the effects of aliasing due to the short vertical wavelength of the tide, and the finite vertical resolution of the radiometer, are correctly accounted for.

Excellent agreement (see Figure 5.1) between observations and theory is obtained for a zonal wind which has a strong jet centered at 80 km and 45° latitude, and which decays dramatically with height. While the observations do not completely determine the form of U, the general features deduced are robust, and are in qualitative agreement with the structure deduced from measurements of the zonal mean temperature structure on the basis of cyclostrophic balance.

A short article describing the highlights of the work has been submitted for publication (ac).

PLANS FY85

Comprehensive articles describing the theoretical background and comparisons with observations will be begun.

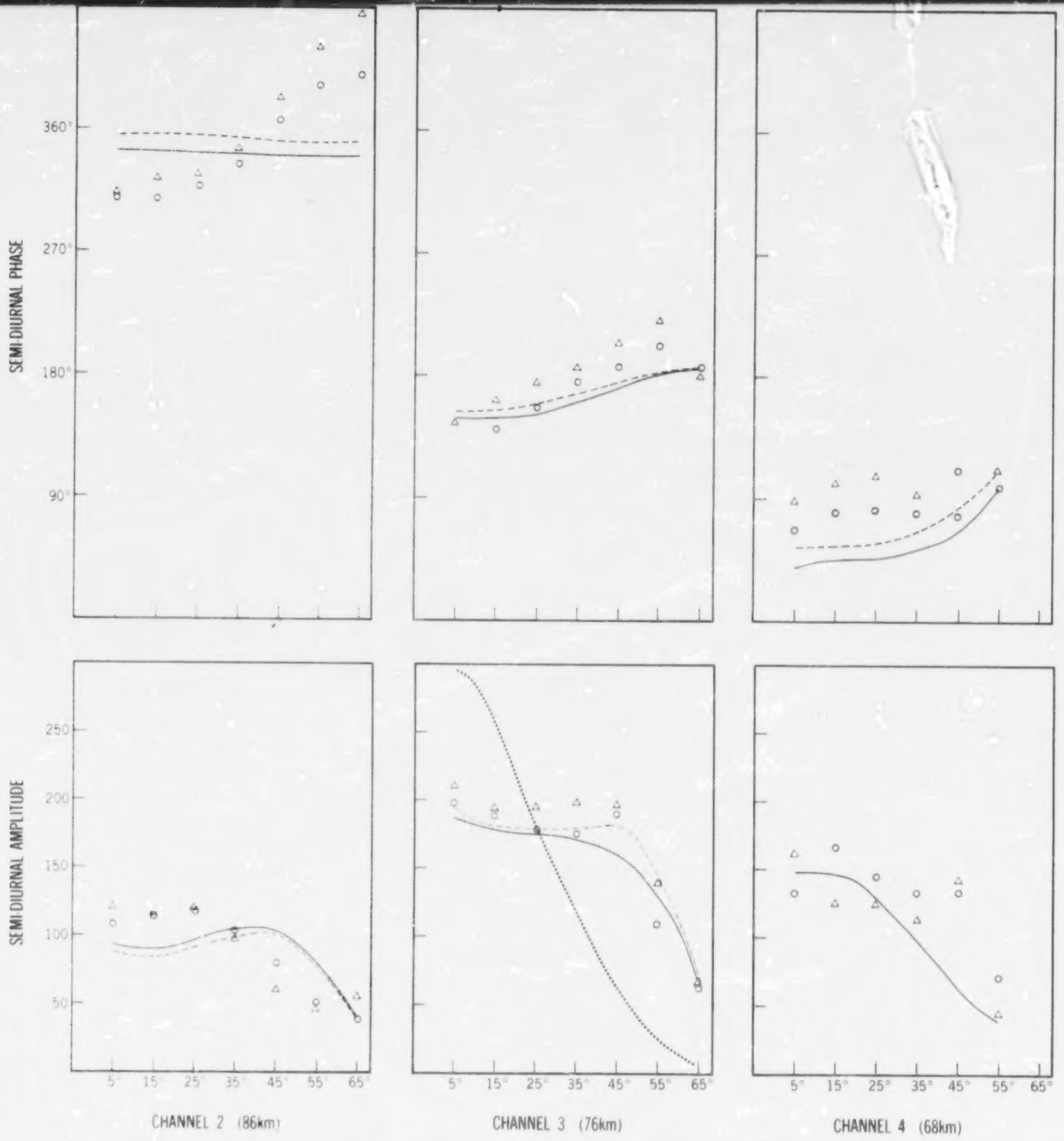

Fig. 5.1--Observed and predicted semidiurnal radiances. The observed mean amplitudes and phases in each of channels 2, 3, and 4 are shown for two different zenith angles (41°- circles; 57°- triangles). The theoretical predictions for these two zenith angles are the solid and chained curves respectively. The amplitudes are in units of nW cm^{-2} $sterad^{-1}/cm^{-1}$, and the phase is measured westward from the sub-solar point. This is a representative sample of the information available for seven different zenith angles. The dotted line in the amplitude diagram for channel 3 shows the meridional structure the tide would have for solid-body rotation.

6. OBSERVATIONAL STUDIES

Goals

- To determine and evaluate the physical processes by which the atmospheric and oceanic circulations are maintained, using all available observations.
- To compare results of observational studies with similar diagnostic studies of model atmospheres and model oceans developed at GFDL and thereby develop a feedback to enhance understanding in both areas.

6.1 ATMOSPHERIC ANALYSES

N.-C. Lau	S. Fagen
A. H. Oort	M. Forman
M. Rosenstein	S. Prasad
	J. P. Peixôto*

* University of Lisbon, Portugal

Review papers were published on the physics of climate (600) and on the diagnostic research projects at GFDL (598). In the first paper the results of both observations and numerical simulations were discussed.

6.1.1 Data Processing and Comparisons Between Various Analyses

The "GFDL Atmospheric Circulation Tape Library, 1958-1973" consisting of 32 magnetic tapes was completed (599), and copies of the Library were sent to the National Climatic Data Center in Asheville, NC, and the National Center for Atmospheric Research in Boulder, CO, for further distribution to the users.

Circulation statistics based on the FGGE level III-b analyses produced by GFDL were compiled and assembled in a comprehensive data report (ab). The systematic differences between the two sets of Level III-b analyses produced by GFDL and the European Center for Medium-Range Weather Forecasting (ECMWF) were documented for the Special Observing Periods (aa). Considerable discrepancies were found between the GFDL and ECMWF analyses regarding the vertical velocity, the intensity of the transient eddies in the tropics, and the temperature of the tropopause.

A further comparison was made for the Special Observing Periods between the GFDL and ECMWF analyses, (both based on four-dimensional data assimilation schemes), and a set of analyses generated by a conventional analysis technique normally used in this project based only on rawinsonde station data (au). Several serious discrepancies between the three analyses were noted.

6.1.2 Transient Eddies, Eddy-Mean Flow Interactions and Angular Momentum Cycle

The structure of transient disturbances and their role in the local kinetic energy budget were examined using various sets of circulation statistics (583, bc). Multi-year observational statistics produced by NMC and GFDL as well as long-term statistics from GCM simulations with and without orography were used. The time scale of the transient eddies determines their anisotropy and affects the nature of the local transfer of kinetic energy between the transient and stationary components. Further, the propagation characteristics of transient disturbances with time scales ranging from a few days to more than a month were studied (597).

An extensive, statistical study of cold-air outbreaks over East Asia was completed. The structure and energetics of the midlatitude disturbances that accompany the outbreaks were analyzed (al).

The global cycle of angular momentum was studied using estimates of the of the friction and mountain torques from both observed and model data generated at GFDL. The seasonal variations in the global torques are in good agreement with astronomical observations of the earth's rotation rate (578). In another study (as) the terrestrial flow of westerly angular momentum from middle to low latitudes required to balance the poleward flow in the atmosphere was shown to take place solely within the solid earth.

6.1.3 Hydrological Cycle and Sea Surface Temperature Studies

The seasonal variations in the hydrological cycle were analyzed, for the first time, separately for the major oceans and continents based on rawinsonde data. Strong meridional divergence (source) of water vapor was found in the subtropics of the two hemispheres both over the oceans and land (v).

Anomalies in the atmospheric and oceanic surface temperatures were analyzed for a 45-year period since May 1920. The sea-air differences exhibit an unrealistic trend showing a way to correct the historical sea surface temperature record for instrumental biases. The study of SST anomalies in the eastern equatorial Pacific and their effects on the global atmospheric circulation was continued (604).

6.1.4 Diagnosis of GCM Results

In cooperation with the Climate Dynamics Project at GFDL, a 15-year GCM experiment was run in which the model atmosphere was subjected to actual SST variations observed in the equatorial Pacific (30°S-30°N) during the period 1962 to 1976. This simulation was found to agree remarkably well with observations, especially over the tropical Pacific (av). These findings are further substantiated by the results of another 15-year GCM simulation with similar lower boundary conditions but with different initial conditions.

The influence of orography on the stationary and transient eddies was studied using history tapes of two 15-year GCM simulations, one with and one without mountains (ak). The orographically forced planetary-scale waves were found to exert considerable steering on synoptic disturbances. The geographical distribution of diabatic heating was affected through modification of the preferred sites of latent heat release.

PLANS FY85

The basic 15-year (1958-1973) and FGGE (1979) data sets will be used in a continuing research effort to study the circulation of the atmosphere and oceans. This will be done through evaluating regional balances of angular momentum, energy and water vapor. Main emphasis will be on indirectly inferred oceanic heat and fresh water transports in connection with the oceanic data studies.

Data processing for a new 5 to 6-year period as a bridge between the 1958-1973 and 1979 (FGGE) periods will continue.

The 6-times a day FGGE analyses generated earlier at GFDL in the Experimental Prediction Group will be studied for the four mid-season months in order to investigate the diurnal cycle in the atmosphere.

Diagnosis of long-term GCM experiments with changing boundary forcing will continue. Model simulations of meteorological phenomena accompanying the El Niño-Southern Oscillation phenomena will be compared with observational results.

The structure of observed and model-simulated transient disturbances and the interactions of these disturbances with the quasi-stationary circulation, will be investigated further. The eddy-mean flow interaction will be interpreted in terms of atmospheric behavior during cold air outbreaks and blocking.

6.2 OCEANIC ANALYSES

S. Levitus A. H. Oort

6.2.1 Data Processing

A tape library with the information contained in the "Climatological Atlas of the World Ocean" (528) was completed and sent to the National Oceanographic Data Center in Washington, D.C., for distribution to the scientific community.

A large set of new Expendable Bathythermograph Data was obtained from the Fleet Numerical Oceanography Center in Monterey, CA, to supplement the GFDL climatological data. The expanded set will allow more definitive studies of subsurface temperature trends in the Northern Hemisphere, and also to better describe the normal annual cycle of temperature in the Southern Hemisphere.

6.2.2 Heat and Salinity Balances

A thorough analysis was made of the annual cycles of temperature and heat storage in the various oceans (601). Some further work using Fourier analyses to delineate the annual cycle is in progress.

In cooperation with the satellite radiation group at Colorado State University, the transport of heat in the oceans and its seasonal variation were investigated for the entire globe using the planetary energy balance method (ae).

A paper describing the annual cycles of salinity and salt storage in the various oceans is in preparation. This information will be a basic input for further studies of seasonal variations in the transport of fresh water in the oceans (v).

6.2.3 Year-to-Year Variability Studies

Time series of subsurface temperatures for selected Marsden Squares in the Atlantic Ocean are being studied for the period since the 1940's. Possible extensions to other oceans and to include the salinity are being considered.

PLANS FY85

In conjunction with the atmospheric branch of the Observational Studies Project, the study of the heat and fresh water balances over individual oceans will continue.

The study of the year-to-year variability in subsurface heat and salt storage will continue.

Sea level estimates will be used for the evaluation of the continental torques in the global angular momentum cycle.

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7. HURRICANE DYNAMICS

GOALS

- To understand the genesis, development and decay of tropical depressions by investigating the thermo-hydrodynamical processes using numerical simulation models.
- To study small-scale features of hurricane systems, such as the collective role of deep convection, the exchange of physical quantities at the lower boundary and the formation of organized spiral bands.
- To investigate the capability of numerical models in the prediction of hurricane movement and intensity.

7.1 GENESIS AND DECAY OF TROPICAL STORMS

M. A. Bender R. E. Tuleya
Y. Kurihara

ACTIVITIES FY84

7.1.1 Decay of Hurricanes

The effects of a mountain range on a landfalling tropical cyclone were studied with the use of a triply nested, movable mesh model with an innermost mesh resolution of 1/6 degree. The integration domain was 45 degrees longitude by 30 degrees latitude, with open lateral boundaries. A mountain range, about 500 km wide, 1 km high and 2000 km long, was placed along the shoreline. The landfall of a tropical cyclone was simulated with the above model for a storm embedded in a mean easterly flow of $\sim 10 \text{ m s}^{-1}$. The integration results were compared with the previous simulation (580) performed without the effect of the mountain range included. Figure 7.1 shows the time variations of the maximum low level wind and minimum sea level pressure of the landfalling storms in the present and previous simulations, respectively. In the experiment incorporating the effects of the mountain, the storm is stronger before the landfall but it fills much more rapidly as it transverses the mountain. Extensive analysis of the mountain effects, including the budgets of kinetic and latent energy for a storm region, was made. It was found that: intense precipitation is induced in the area where the strong wind is up along the mountain slope; the mountain range affects the moisture content of the boundary layer and the wind field to reduce the convergence of latent energy; a low-level, warm and dry region was produced at the lee side of the mountain.

In order to better isolate the influence of the mountain on the mean easterly flow, the model was also integrated for the flow without the storm. The mountain causes a significant modification of the basic flow not only over the mountain but also up to several hundred kilometers downstream and extending considerably above the mountain ridge. A low level southerly jet forms to the west of the mountain base. Such a phenomenon apparently influences the movement of a storm.

7.1.2 Genesis of Hurricanes

A study on the transformation of a tropical easterly wave to a tropical depression was continued. A simple numerical model was integrated with the inclusion of the nonlinear effect, the CISK-type heating effect and those two effects combined; three such integrations were performed for 15 cases, i.e., with respect to each of three waves having different structures for five different basic flow conditions. In all cases, the diabatic heating is apparently a necessary ingredient for the development of a depression in the region of a surface pressure trough. The nonlinearity process on a vertical plane could make a positive contribution to the wave transformation only in the presence of heating. It was found that the basic flow having easterly vertical shear tends to be more favorable for wave development than the one with westerly shear; this agrees with a result obtained in the three-

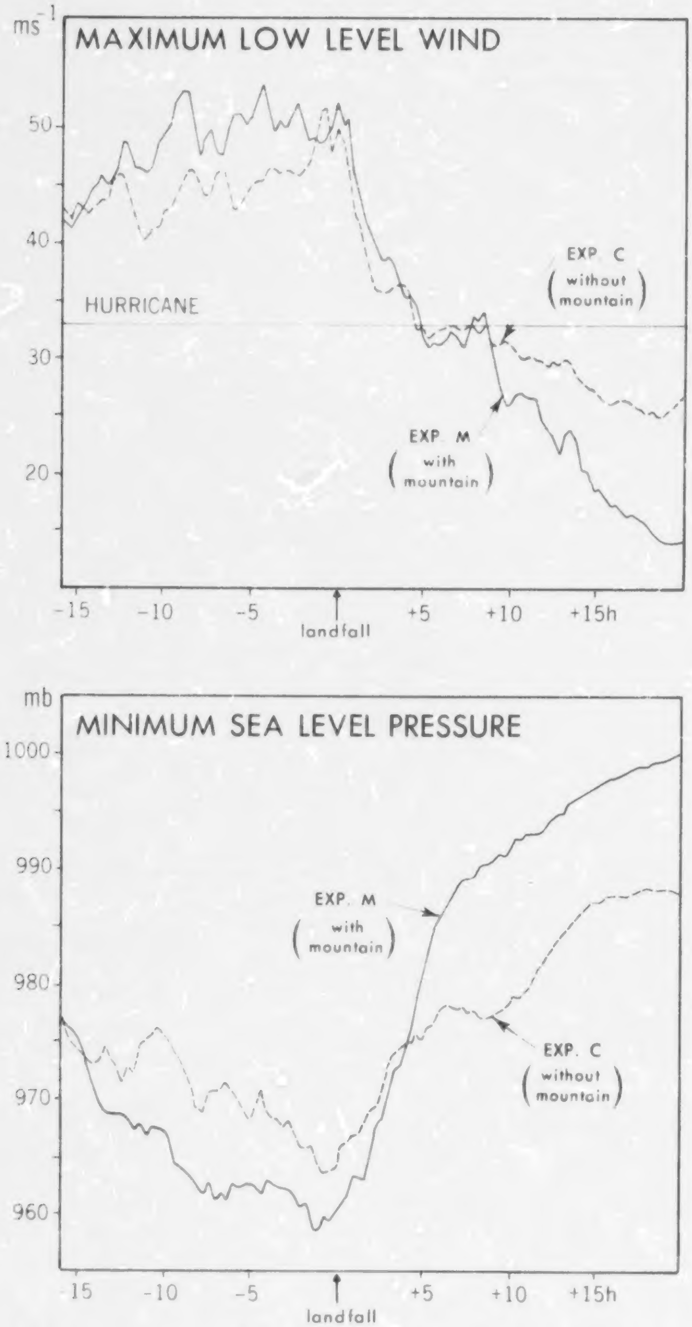

Fig. 7.1.-- Top: Time variation of the maximum low level wind of a landfalling tropical cyclone in the experiment incorporating the effects of the mountain (Exp. M, solid line), and in the one without them (Exp. C, dashed line). Bottom: Same as top, except the minimum sea level pressure.

dimensional simulation experiments (483). Thus, it was again suggested that the coupling between the upper level wind and the propagating disturbance at low levels might be an important mechanism in the formation of a tropical depression in the trough region of an easterly wave.

7.1.3 Hurricane David

An investigation of the evolution of Hurricane David, 1979, was initiated with the preparation of a numerical model and actual initial data. The model was designed to cover the domain of 36 degrees longitude by 30 degrees latitudes with the resolution of 1/4 degree. The initial condition was obtained from the FGGE Level III-b global data set produced at GFDL (see 7.2). Preliminary integration of the model has just begun.

PLANS FY85

A study on the mountain effects on the landfalling hurricanes will continue through further analysis of the numerical results obtained from the model integrations.

Numerical experiments will be conducted with the newly designed model in order to investigate the development processes of Hurricane David.

7.2 EXPERIMENTAL HURRICANE PREDICTION

M. A. Bender R. E. Tuleya
Y. Kurihara

ACTIVITIES FY84

Hurricane David was selected as the first case of experimental prediction of a tropical cyclone. In the retrieval of data for this case from the FGGE Level III-b data set processed at GFDL, a scheme had to be formulated for data conversion between different systems. It was found that the interpolation of data on sigma surfaces can be achieved rather well when an interpolating function is used which is continuous and has continuous first order partial derivatives. The investigation of the treatment of the open lateral boundary of a limited area primitive equation model was continued. Attention was given to the budget of total mass in an integration domain.

As a part of the model initialization system, a method was tested which should efficiently establish the boundary layer wind field.

PLANS FY85

The detailed specification of the lower boundary conditions, such as the sea surface temperature and the orography, will be attempted.

8. MESOSCALE DYNAMICS

GOALS

- To produce accurate numerical simulations of mesoscale processes in order to understand what role synoptic scale parameters play in their generation and evolution.

- To understand the dynamics of mesoscale phenomena and their interaction with larger and smaller scales.

- To determine practical limits of mesoscale predictability by means of sensitivity studies on numerical simulations of mesoscale phenomena.

8.1 FRONTAL DYNAMICS

I. Orlanski L. Polinsky
B. B. Ross R. Shaginaw

ACTIVITIES FY84

A simulation of a cold front, which occurred over the central U. S. on 26 April 1979 and was observed in the SESAME field experiment, has been produced using FGGE initial and boundary data (aw). The results from this solution have been compared, in a one-to-one manner, with the detailed analysis of Ogura and Portis.† The overall structure of the simulated front shows many similarities to that of the analyzed front.

Analysis was also made of the frontogenetical and frontolytical forcing terms which determine the intensity of the horizontal temperature gradient in the front. The adiabatic terms show reasonable agreement with observations. Analysis of the numerical simulation showed that the tilting term, the largest of the adiabatic terms, is largely counteracted by diabatic effects due to moist convection (Figure 8.1). This result agrees with the findings from an earlier analysis of a moist front simulation (613).

The complete analysis shows that two regions of frontogenesis occurred on the warm side of the front, one near the surface due to convergence and deformation, and the other in the middle of the troposphere due to an excess of diabatic over tilting effects. Frontolysis was produced at middle levels on the cold side of the front, due primarily to tilting and diffusive effects.

A comparison of the vertical structure of the cold front with and without moisture showed the frontal structure to penetrate deeper into the atmosphere in the moist than in the dry case. The numerical solutions indicated that the main circulation follows shallower isentropic surfaces in the dry case, whereas air parcels follow steeper moist pseudo-adiabats in the moist (saturated) atmosphere, thereby modifying the entire cross-stream circulation.

PLANS FY85

The role of latent heat in frontogenesis will continue to be investigated.

8.2 MESOSCALE PREDICTABILITY

8.2.1 Meso-α Predictability

I. Orlanski
L. Polinsky

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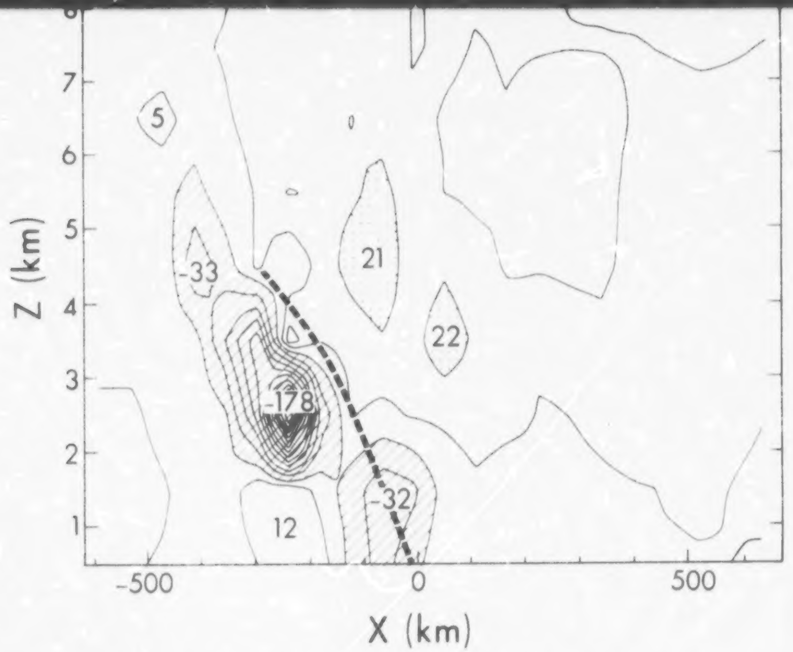
† Ogura, Y., and D. Portis, 1982: Structure of the cold front observed in SESAME III and its comparison with the Hoskins-Bretherton frontogenesis model. J. Atmos. Sci., 39, 2773-2792.



(b) FRONTOGENETICAL FUNCTION

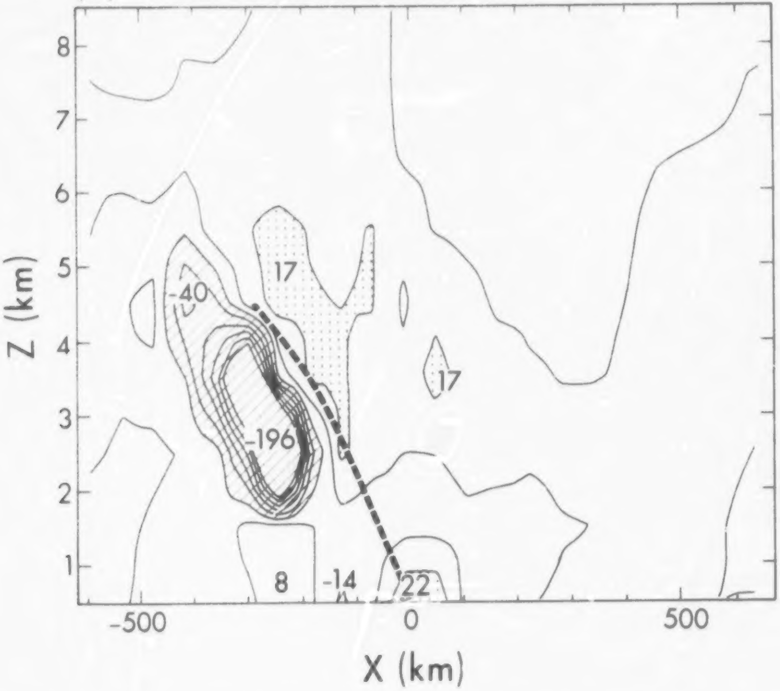


Figure 8.1 -- Vertical cross-sections through the simulated cold front of 26 April 1979 showing (a) combined diabatic and tilting terms and (b) total frontogenetical function, both in units of 10^{-10} K $m^{-1}s^{-1}$. Frontogenetical effects (stippling) are shown at ground level and upper levels ahead of the front, whereas frontolytical effects (cross-hatching) are shown behind the front. The effects at the ground produced by adiabatic processes (convergence and deformation) and the frontolytical effects (tilting) had been speculated from idealized studies. The upper frontogenetical effects ahead of the front produced by latent heat release (diabatic processes) are shown for the first time by this study.

ACTIVITIES FY84

A number of simulations with a high resolution three-dimensional primitive equation model have been carried out to assess the impact of initial and boundary data inaccuracies for the simulation of meso-convective systems (MCS's) and their environments (ah). In particular, simulations have been performed for the following types of phenomena: The Pacific comma cloud, frontal squall lines, meso-convective complexes and coastal cyclogenesis. All cases occurred during 1979, the year of the FGGE Experiment.

The sensitivity of these simulations to surface boundary layer variables (relative humidity at the ground) and assumed cloud fraction (a method for parameterizing latent heat effects) has been investigated. Considerable success has been achieved for these simulations in reproducing the observed evolution of mesoconvective systems. In this study, an investigation was made to determine how different moisture fields at the ground can affect the evolution of MCS's; it was found that the position of vorticity centers is unaffected by the moisture field. In most meso-convective systems, the environmental convergence of a pre-existing front is responsible for the growth of the storm's vorticity, whereas latent heat release is required to produce explosive storm growth.

PLANS FY85

The investigation of the impact of surface data quality on quantitative precipitation forecasts will continue.

8.2.2 Meso-β Predictability

B. B. Ross

ACTIVITIES 84

A meso-β scale simulation of mesoscale convective systems over Oklahoma and Texas has produced a realistic simulation of precipitation and cloud patterns during the period 10-11 April 1979, the first observing day of the SESAME field experiment. The success of this simulation in reproducing the observed squall line was found to be due largely to the use of observed SESAME wind and temperature data in the initial and boundary conditions to properly represent the cold front which triggered the convection. Although the alignment of the system is controlled by the dynamics of this front, the structure and intensity of the convection in the simulated squall line was found to be quite sensitive to the moisture supply upwind of the system.

Two convective systems are identifiable in the simulation. The first was associated with moisture convergence over north-central Texas late on 10 April and moved to the north-northeast. The second developed over west-central Texas in the vicinity of an eastward-moving cold front and dry line early on 11 April and formed a nearly stationary squall line in the observations.

PLANS FY85

Detailed analysis will be made of the SESAME-I simulations by studying parcel trajectories and equation terms and by employing different representations of explicit convection and surface conditions in order to better define the dynamic and thermodynamic structure of the mesoscale convective systems.

Meso-β simulations of other mesoscale convective systems observed during the SESAME experiment will also be produced and analyzed.

8.3 COASTAL CYCLOGENESIS

I. Orlanski
D. Miller
J. Katzfey

ACTIVITIES FY84

The realistic development of coastal cyclogenesis is under investigation by means of a limited-area model (HIBU) nested in a global spectral model.

A very intense and rapidly developing cyclone which produced the greatest 24h snowfall accumulation in Washington, D.C. for more than 50 years happened on 19 February 1979 and is referred to as the President's Day Snowstorm. Cyclogenesis began northeast of Florida, leading to the formation of a cyclonic circulation east of Charleston. Cyclogenesis intensified as the storm moved slowly north-northeastward with an explosive deepening. This storm can be considered an extreme event for coastal cyclogenesis in the Eastern United States; however, frequent cyclogenesis in winter and spring is observed.

The 48-hr simulations of the limited-area model seem to have captured the explosive behavior of the cyclone. Whereas the present GFDL spectral model and the FGGE analysis had not shown much deepening of the surface low (a minimum of only 1006 mb), the HIBU model develops a deeper low (<1000 mb).

PLANS FY85

Speculation has been made as to which processes are responsible for the explosive cyclogenesis found in this case. Further investigation will be made using the numerical simulations in order to identify the cause of this evolution.

8.4 MODEL DEVELOPMENT

I. Orlanski
B. B. Ross
L. Polinsky
J. Katzfey
F. Mesinger

ACTIVITIES FY84

The MAC/BES mesoscale model has been enhanced in several ways. A method for prescribing cloud fraction amounts in the vertical has been implemented as a means of parameterizing the effect of latent heat release in the explicit convection representation used in the model. A scale-selective fourth-order diffusion has been added to damp out large horizontal wave numbers in the model solutions. Also, an improved formulation of the lateral boundary treatment of divergence was incorporated and was shown to increase the stability of the model solutions. Code used to parameterize mountain drag effects was converted to the Cyber computer system.

The advection scheme and the treatment of mountains in the HIBU model have been modified.

PLANS FY85

The design of the MAC/BES mesoscale model will be reviewed and modified for the purpose of improving model formulation and lateral boundary treatment. During this review, changes will also be made to improve its efficiency on the Cyber system.

9. CONVECTION AND TURBULENCE

GOALS

- To develop and improve three-dimensional numerical models capable of simulating dry and moist thermal convection in the atmosphere.
- To understand the dynamics of deep moist convection and its role in the vertical transfer of heat, moisture, momentum and atmospheric tracers.
- To develop numerical models capable of simulating turbulence in homogeneous and stratified fluids by simulating the large turbulent eddies directly and by testing various parameterizations of the subgrid-scale flow.
- To perform laboratory measurements and analysis of turbulence in various media to aid understanding of its fundamental mechanisms.
- To formulate and test against observation various turbulence closure hypotheses applicable to the diabatic planetary boundary layer.

9.1 MOIST CONVECTION

R. S. Hemler
F. B. Lipps

ACTIVITIES FY84

9.1.1 Simulation of Continental Convection

An essential project this year has been to complete the development and testing of the numerical model with open lateral boundary conditions. This work has included generalizing analysis routines so that the energetics and other model diagnostics can be obtained for either open or periodic lateral conditions. The present algorithm for open lateral conditions has been tested in the simulation of a long-lasting cloud. It has been demonstrated that the present scheme works well compared with other choices for open boundary conditions.

The basic structure of the present numerical model is described in (516) and (303) with subsequent modifications in the subgrid-scale turbulence and the addition of open lateral boundary conditions. This model is being used to simulate three-dimensional continental convection observed in the Central United States. For these calculations the horizontal domain is 48 km by 32 km and the model depth is 17 km. The horizontal grid lengths are 1.0 km in both directions and the vertical grid interval is 0.5 km. The convection is initiated by a saturated bubble in the center of the horizontal domain and confined in the vertical between 1.75 km and 4.75 km. The maximum disturbance potential temperature in the bubble is 0.75 K and is located at 3.25 km.

Model calculations have been carried out with unidirectional wind shear and varying wind shear direction. For both open and periodic lateral boundary conditions results thus far have been similar: A strong single cell cloud develops which gives maximum precipitation of approximately 1.0 cm with rainfall lasting for one-half hour. The strongest updraft is about 27 m/sec and the largest potential temperature excess is approximately 7.5 K. Both of these features occur near 7.5 km above the surface. The maximum cooling at the ground is 5.5 K which is about one-half of the observed value. The primary deficiency of the present calculations is the absence of secondary cell development on the leading edge of the gust front when open lateral boundary conditions are used. Such secondary development is expected from observations and other simulations. Efforts are now underway to correct this shortcoming of the present model results.

For the above model simulations, a preliminary examination of the vertical momentum transfer due to moist convection has been made. In all cases the momentum flux is downgradient, with the maximum damping of the mean winds due to momentum flux convergence of 1 m/sec per day. The present model results have been compared with simple expressions for the parameterization of cumulus friction. Analysis of the above calculations strongly suggests that the assumption of undilute parcel ascent applied to momentum transfer is poor in regions of moderate to strong wind shear. In regions of weak shear, this assumption may be acceptable.

Finally, a manuscript clarifying some aspects of the scale analysis (516) is undergoing internal review before submission for publication.

9.1.2 Further Analysis of GATE Convection

It was decided that a more detailed analysis of the vertical velocity data be carried out for some earlier simulations of GATE convection (588). In conformity with observational studies, vertical velocity cores have been analyzed for both updrafts and downdrafts, where a core is defined as a vertical velocity cell of at least 0.5 km width with the magnitude of the vertical velocity greater than 1 m/sec. For the three-dimensional numerical simulation, updraft cores are in reasonable agreement with observations at mid-vertical levels, but are weak at 1.5 km and below. The simulated downdraft cores are weak at all vertical levels.

A primary objective of this research and of the research described in 9.1.1 is to determine how moist convection acts to transfer water vapor, heat and momentum in the vertical as well as to account for precipitation and evaporation at the surface. A long-term goal is to use the knowledge gained from convection modeling to improve cumulus-scale parameterizations in mesoscale and larger-scale numerical models.

9.1.3 Passive Tracer Study

The above set of calculations for continental convection has also been used to examine the vertical mixing of a passive tracer due to deep convection. The initial distribution of tracer is a uniform concentration from the surface to 1.75 km and no tracer above that level. Due to the transient nature of the simulated convection, results are similar whether open or periodic boundary conditions are used. A bimodal distribution of tracer concentration is set up in the vertical, with a secondary maximum in the layers of convective outflow. However, only about 1.5 percent of the total mass of the original tracer distribution is associated with the upper level maximum. By far the bulk of the tracer concentration remains in the boundary layer and in the layers just above.

The vertical mixing of a passive tracer was also calculated for the idealized vertical sounding which resulted in the long-lasting cloud, used to test the open boundary conditions. Since this cloud is quasi-steady, the results were significantly different than discussed above with a strong mean inflow of tracer into the boundary layer and strong outflow above it. The primary outflow is contained in a layer 3 km deep just above the boundary layer of 1.75 km. For this 90 minute simulation, 15 per cent of the initial total tracer mass participates in the inflow-outflow circulation.

PLANS FY85

Calculations presently being carried out to simulate continental convection in the Central United States will be completed. It is anticipated that more realistic results will be obtained with secondary convection developing on the leading edge of the gust front. A cooperative effort will be carried out with the Mesoscale Dynamics Group to simulate an observed case of deep moist convection. Their meso-β scale model will supply the large-scale flow and side boundary conditions for the present model. In this way an attempt will be made, using the present model, to simulate the observed meso-γ scale convection.

The examination of the vertical momentum transfer and kinetic energy transformation associated with the interaction of vertical wind shear and deep moist convection will continue. A comparison of the results for single, transient cells with those having a quasi-steady behavior will be made.

Calculations will be carried out to test the sensitivity to initial conditions for the convection observed on Day 226 of GATE. This work is in conjunction with the International Cloud Modeling Workshop of the World Meteorological Organization.

The passive tracer study will continue with a more detailed analysis for the case of quasi-steady convection. The effect of water solubility will be included. In addition, the downward advection of tracer from the upper atmosphere due to deep convection will be examined.

9.2 ATMOSPHERIC AND OCEANIC BOUNDARY LAYERS

B. Rajkovic
G. L. Mellor

ACTIVITIES FY84

Work on the development of a two-dimensional coupled ocean-atmosphere model is continuing. The atmospheric portion has been tested with the diurnal cycle of land surface temperature forcing. In the case of zero mean winds, the calculated land-sea breeze showed qualitative agreement with observed data. The wind stress at the lowest level was of the order of -.05 dynes/cm^2 and that has produced a sea surface temperature change of 1.5 K due to upwelling near the coastline.

PLANS FY85

The atmospheric part will be initialized with observed mean winds and temperature profiles from the CODE experiment. Other data from that experiment will be compared with model results. Finally, the coupled model will be run and results will be compared with CODE data.

9.3 COASTAL AND ESTUARINE OCEANOGRAPHY

G. L. Mellor L.-Y. Oey
B. Galperin

ACTIVITIES FY84

A three part paper (609; (a); (h)) which describes a time-dependent, three-dimensional numerical study of the Hudson/Raritan estuary has been completed. The calculation covers July through September, 1980, and includes real tide and wind forcing and also time-dependent river and sewer discharges. Turbulence mixing coefficients in the estuary are calculated according to a second moment, turbulence closure sub-model. The model requires no horizontal diffusion due to its small horizontal (500m) and vertical (10 σ-coordinate levels) grid intervals. Part I describes the model, the resulting velocity and current fields and details of tide and wind driven mixing of oceanic salt water with upriver fresh water. Hydrographic observations compare favorably with calculations. Part II compares model calculations with NOS tidal elevation and current meter data. In particular, amplitude and phase of the major tidal constituents are analyzed. Subtidal wind forcing is also analyzed. The errors are quite small except in well defined regions where resolution is poor. Part III is an analysis of the various processes which contribute to salt flux and dispersion in the esturary.

A two-dimensional study of the coastal upwelling problem has been completed using alongshore, wind stress elevation gradients and density gradients derived from observations of the California Current System. One finding is that wind stress curl plays an important role in determining the alongshore current structure.

PLANS FY85

Work on a three-dimensional model of the Delaware estuary - which was suspended in 1984 - will be restarted. The model will include Delaware Bay and River and also a large portion of the continental shelf adjacent to the mouth of the Bay. The barotropic portion of the model will be part of a forecast system which The National Ocean Service hopes to be operational at the beginning of FY85.

Work will begin on ocean-ice interaction using the turbulence closure model in one dimensional and two-dimensional simulations of Arctic, marginal ice zone dynamics.

APPENDIX A

GFDL Staff Members

and

Affiliated Personnel

during

Fiscal Year 1984

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J. D. Mahlman, Acting Director	5/24/84 - 9/30/84	FTP
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Isidoro Orlanski, Acting Director	10/1/83 - 5/23/84	FTP
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Alan R. Thomas, Associate Director		FTP*

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* Affiliation Terminated Prior to September 30, 1984

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Rosenstein, Melvin	Sr. Technician	FTP

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Steele, Michael	Student	PU

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Galperin, Boris	Visiting Scientist	PU
Oey, Lie-Yauw	Research Staff	PU*
Rajkovic, Borivoje	Student	PU

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Callan, Johann	Secretary	PU
Chang, Ping	Student	PU
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Hellerman, Solomon	Computer Programmer PT	PU
Kawase, Mitsuhiro	Student	PU
Key, Robert	Research Staff	PU
Nakamura, Noburo	Student	PU
Olsen, Esther	Secretary	PU
Papademetriou, Demetra	Student	PU
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Romer, Evan	Computer Programmer	PU*
Slater, Richard	Computer Programmer	PU
Toggweiler, John	Visiting Scientist	PU

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Siebers, Bernard	Senior Analyst	CDC
Stringer, John	Analyst in Charge	CDC
Clark, David	Systems Analyst	CDC*
Davis, Robert	Systems Analyst	CDC*
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Thompson, Robert	Senior Customer Eng.	CDC
Weiss, Edward	Senior Customer Eng.	CDC

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PERSONNEL SUMMARY

September 30, 1984

FTP - Full Time Permanent (GFDL)	82
PTP - Part Time Permanent (GFDL)	3
WAE - When Actually Employed (GFDL)	3
Junior Fellows (GFDL)	10
Visiting Scientists (PU)	12
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*In collaboration with other organizations

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APPENDIX C

Computational Support

APPENDIX C

Computational Support

The principal event in computational support during FY84 was the delivery and acceptance of a second CYBER 205 in November and December 1983. The second 205 has been designated CY4, because it has 4 million words of memory. The first 205 is now CY2, because it has only 2 million words of memory. The number of terminals on the the CYBER System was roughly doubled at the end of January 1984.

The CYBER System has proven to be fairly reliable. Further improvement in reliability is needed, however, for magnetic tape and for the link between the front-end 170 and the 205's. New operating software, to be installed at the end of FY84 or early in FY85, is expected to facilitate greater reliability and operability. The guaranteed combined availability of both 205's increases from 42 hours per day to 44 hours per day in December 1984.

FY85 should witness continued, gradual improvement of reliability and usability of the CYBER machines.

Table C-1. Achieved CPU Hours for GFDL Machines

Month	CYBER 170	CY2	CY4
Aug 83*	287	508	-
Sep 83*	190	453	-
Oct 83	228	522	-
Nov 83	231	502	302
Dec 83	264	568	575
Jan 84	351	563	586
Feb 84	294	584	569
Mar 84	351	575	637
Apr 84	337	537	575
May 84	326	566	544
Jun 84	321	563	531
Jul 84	331	333	549
Aug 84	371	550	643
Sep 84	**	**	**

* Not reported in the FY83 Annual Report
** Not available at press time

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APPENDIX D

Seminars Given at GFDL
During Fiscal Year 1984

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Seminars not included in FY83 Report

13 September 1983	"Modeling Sea Surface Temperature with Application to Storm Induced Changes" by Dr. R. Greatbatch, Geophysical Fluid Dynamics Program, Princeton University
15 September 1983	"The Propagation of Stationary and Transient Eddies" by Dr. R. Alan Plumb, Geophysical Fluid Dynamics Program, Princeton University
20 September 1983	"A Numerical Simulation of the Mean Circulation of the Middle Atmosphere Including Effects of the Solar Tides and Gravity Waves" by S. Miyahara, Geophysical Fluid Dynamics Program, Princeton University
22 September 1983	"Persistent Anomalies: Temporal Variability and Characteristic Life Cycles" by Dr. Randy Dole, Center for Meteorology and Physical Oceanography, Massachusetts Institute of Technology, Cambridge, MA

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4 October 1983	"Atmospheric ^{210}Pb as a Tracer of Aerosols" by Dr. K.K. Turekian, Department of Geology and Geophysics, Yale University, New Haven, CT
13 October 1983	"Mechanics of Fold-and-Thrust Mountain Belts and Submarine Accretionary Wedges" by Prof. F. A. Dahlen, Jr., Dept. of Geological and Geophysical Sciences, Princeton University
14 October 1983	"Spin-up Simulation in Isobaric and Isopycnal Coordinates" by Prof. Rainer Bleck, Rosensteil School of Oceanography, University of Miami, Miami, FL
21 October 1983	"Studies of FGGE Data: Estimates of the Reliability of GC Statistics, and a Descriptive Study of a 30-50 Day Tropical Mode" by Dr. Andrew Lorenc, United Kingdom Meteorological Office, England
24 October 1983	"Sensitivity of Middle and High Latitude Forecasts to Tropical Data" by Takeo Kitade, Florida State University
25 October 1983	"Dynamical Predictability of Ensemble Means" by Dr. Y. Hayashi, Geophysical Fluid Dynamics Program, Princeton University

1 November 1983	"Particle Dispersal and Lagrangian Conservation of Vorticity in Models of Beta-Plane Turbulence" by Dr. Dale Haidovogel, NCAR, Boulder, CO
4 November 1983	"Turbulence and Wave Motions near an Interface at the Top of the Atmospheric Boundary Layer" by David J. Carruthers, University of Cambridge, Dept. of Applied Mathematics & Theoretical Physics, Cambridge, England
10 November 1983	"On the Control of Atmospheric pCO_2 by High Latitude Regions of the Ocean" by Dr. J.R. Toggweiler, Geophysical Fluid Dynamics Program, Princeton University
14 November 1983	"Atmospheric Response to Large Sources of Radiatively and Chemically Active Pollutants" by Dr. J. Mahlman, Geophysical Fluid Dynamics Laboratory
15 November 1983	"Stationary External Rossby Waves in the Troposphere" by Dr. I. Held, Geophysical Fluid Dynamics Laboratory
17 November 1983	"Dropwindsonde Observations of the Steering Currents of Hurricane Debby (1982) by Dr. Robert W. Burpee, Atlantic Oceanographic & Meteorological Lab., Miami, FL
21 November 1983	"Effects of Global Warming on Australian Biospheric Productivity" by Dr. A. Barrie Pittock, CSIRO, Mordialloc, Victoria, Australia
21 November 1983	"Treatment of Clouds in General Circulation Models" by Dr. Hilding Sundquist, Department of Meteorology, Stockholm, Sweden
22 November 1983	"Adjustment of the Ocean under Buoyancy Forces" by R. Wajsowicz, Geophysical Fluid Dynamics Program, Princeton University
28 November 1983	"Forced Double Kelvin Waves in a Stratified Ocean" by Dr. Andrew J. Willmott, Dept. of Mathematics, University of Exeter, England
29 November 1983	"On the Mean Wind Induced by Internal Gravity Wave Packets in the Atmosphere" by Dr. S. Miyahara, Geophysical Fluid Dynamics Laboratory, Princeton University
29 November 1983	"Application of a Semi-Implicit and Semi-Lagrangian Integration Scheme to a Limited Area Atmospheric Model" by Dr. Andre Robert, Dynamic Prediction Research Div., Dorval, Quebec, Canada

5 December 1983	"A Combined 3D Instability Theory of the Onset of Blocking, Cyclogenesis, and Teleconnection Patterns" by Joergen S. Frederiksen, CSIRO, Div. of Atmospheric Physics, Victoria, Australia
6 December 1983	"Objective Derivation of the Zonally-Averaged Transport Characteristics of a GCM" by Dr. A. Plumb, Geophysical Fluid Dynamics Program, Princeton University
8 December 1983	"Sea Level Pressures and Southern Oscillation" by Prof. T.N. Krishnamurti, Florida State University, Tallahassee, FL
13 December 1983	"Local and Global Baroclinic Instability of Zonally Varying Flow" by Dr. R. Pierrehumbert, Geophysical Fluid Dynamics Laboratory
12 January 1984	"NMC: Current Operations and Plans for the Future" by Dr. William Dr. Bonner, National Weather Service, Washington, DC
23 January 1984	"Numerical Simulation of Influences of 1982-83 El Nino Sea Surface Temperature Anomaly" by Prof. J. Shukla, Department of Meteorology, University of Maryland, College Park, MD
26 January 1984	"Low Frequency Variability in Thermally Forced Phenomena" by Prof. Peter Webster, Pennsylvania State University, University Park, PA
31 January 1984	"The Sensitivity of Low Latitude Velocity Potential Field in a NWP Model" by Dr. K. Puri, Geophysical Fluid Dynamics Program, Princeton University, Princeton, NJ
2 February 1984	"Gyre Scale Acoustic Tomography: Modelling Simulations The Heat Content of the Eastern Ocean" by Prof. Paola M. Rizzoli, Oceanography Dept., M.I.T., Cambridge, MA
7 February 1984	"Simulation of Turbulent Flows and Turbulent Diffusion by Simple Turbulent Energy Model" by Dr. B. Galperin, Geophysical Fluid Dynamics Program, Princeton University, Princeton, NJ
15 February 1984	"SST Experiments with the NCAR Community Climate Model" by Dr. Maurice Blackmon, National Center for Atmospheric Research, Boulder, CO
23 February 1984	"Thermocline Structure in the Subtropic/Subpolar Gyres" Mr. Rui Xin Huang, M.I.T., Cambridge, MA

[illegible] March 1984	"Tropospheric Ozone" by Dr. H. Levy II, Geophysical Fluid Dynamics Laboratory/NOAA, Princeton, NJ
8 March 1984	"Simulation of the Deuterium and Oxygen 18 Cycles using a GCM" by Dr. Jean Jouzel, GISS, 2880 Broadway, New York
16 March 1984	"An Overview of Inverse Methods in Oceanography" by Dr. Manuel Fiadeiro, Geology Dept., Yale University,
20 March 1984	"Numerical Diagnostic Studies of GATE Synoptic Scale Disturbances" by Prof. Robert S. Ross, University of PA Millersville, PA
22 March 1984	"An Objective Analysis of Clouds from Satellite Imagery Data" by Dr. James A. Coakley, Cloud-Climate Interaction Group, NCAR, Boulder, CO
29 March 1984	"Tracer Studies with a GCM: Trends and Variability in Tropospheric Fluorocarbons" by Dr. Michael J. Prather, Harvard University, Center for Earth & Planetary Physics, Cambridge, MA
6 April 1984	"Moist Frontogenesis in a Semi-Geostrophic Model" by Dr. Mankin Mak, NCAR, Boulder, CO
12 April 1984	"Obtaining Climatic Sensitivity from Atmospheric Data using the Fluctuation-Dissipation Relation" by Dr. Thomas L. Bell, Climate and Radiation Branch/NASA, Goddard Space Flight Center, Greenbelt, MD
13 April 1984	"A Barotropic Study of Waves and Turbulence in a Stationary Zonal Jet" by Dr. Theodore Shepherd, Center for Meteorology & Physical Oceanography, Massachusetts Inst. of Technology, Cambridge, MA
17 April 1984	"Breaking Kelvin Waves and Solitary Rossby Waves in the Equatorial Oceans" by Dr. Richard Greatbach, Geophysical Fluid Dynamics Program, Princeton University, Princeton, NJ
19 April 1984	"An Axisymmetric, Nonhydrostatic Tropical Cyclone Model with a Parameterized Ice-Phase Microphysics" by Dr. Stephen J. Lord, AOML, Hurricane Research Div. 4301 Rickenbacker Causeway, Miami, FL
26 April 1984	"Distributions of Bomb Radiocarbon and Tritium in the Ocean" by Prof. W.S. Broecker, Lamont-Doherty Geological Observatory, Palisades, NY

2 May 1984	"The Australian (North West) Monsoon - A Synoptic/Diagnostic Study" by Dr. Bryan J. McAvaney, Australian Numerical Meteorology Research Center, Melbourne, Victoria, Australia
3 May 1984	"Regional Dynamics, Data Assimilation and the POLYMODE Synoptic-Dynamics Experiment" by Prof. Alan Robinson, Div. of Applied Sciences, Harvard University, Cambridge, MA
22 May 1984	"El Niño y La Niña, by Dr. George Philander, Geophysical Fluid Dynamics Laboratory, Princeton, NJ
24 May 1984	"An Approach for Validating GCM's of Satellite Radiation Data" by Dr. V. Ramanathan, NASA, Langley Research Center, Hampton, VA
29 May 1984	"Interannual Variability and the Management of Fraser River Salmon Resources" by Dr. Kevin Hamilton, University of British Columbia
29 May 1984	"Dynamics of the Tropical Stratosphere" by Dr. Kevin Hamilton, University of British Columbia
31 May 1984	"A Moist Convective Parameterization based on Saturation Point Adjustment: Preliminary Tests using GATE Data" by Dr. Alan K. Betts, ECMWF, Reading, England
5 June 1984	"Response of a Simple Model to Tropical Heating" by Dr. R.N. Keshavamurti, Physical Research Laboratory, Navrangpura, India
7 June 1984	"Philosophy and use of Anomaly Climate Models" by Dr. H.M. van den Dool, Dept. of Meteorology, University of Maryland, College Park, MD
12 June 1984	"Annual Cycle of Temperature and Heat Storage in the World Ocean, by Sydney Levitus, Geophysical Fluid Dynamics Laboratory, Princeton, NJ
14 June 1984	"Cumulus Parameterization in Mesoscale Models" by Prof. William M. Frank, Pennsylvania State Univ. Dept. of Meteorology, University Park, PA 16802
19 June 1984	"A Numerical and Observational Study of Tides, Circulation and Salt Transport in the Hudson-Raritan Estuary" by Dr. L.Y. Oey, Geophysical Fluid Dynamics Program, Princeton University, Princeton, NJ.

21 June 1984	"Dynamics and Energetics of Lee Cyclones during ALPEX" by Dr. John McGinley, University of Oklahoma, Norman, OK
2 July 1984	"The Various Barotropic and Baroclinic Geostrophic Regimes in the Ocean and Atmosphere" by Dr. Benoit Cushman-Roisin, Dept. of Meteorology, Florida State University.
6 July 1984	"Numerical Simulations of Sudden Warmings" by Dr. C. Roberto Mechoso, University of California, Los Angeles
16 July 1984	"On the Structure of Low-Frequency Variability in the General Circulation" by Dr. John M. Wallace, Dept. of Atmospheric Sciences, University of Washington
26 July 1984	"Direct Numerical Simulation of 2-D Turbulence" by Dr. P. Sulem, Courant Inst. of Mathematical Sciences, New York.
7 August 1984	"Tropical 40-50 Day Oscillations during the 1979 Summer" by Dr. T. Nakazawa, Dept. of Meteorology, University of Hawaii, Honolulu, HI.
16 August 1984	"Explosive Baroclinic Instability in a Two-Layer Model with Weak Ekman Friction" by Prof. Lee-Or Merkine, Technion, Israel Institute of Technology, Israel.
21 August 1984	"Representation of Mountains in Numerical Models" by Prof. F. Mesinger, Geophysical Fluid Dynamics Program, Princeton University, Princeton, NJ
24 August 1984	"Numerical Simulation of a Genoa Lee Cyclogenesis" by Prof. F. Mesinger, Geophysical Fluid Dynamics Program, Princeton University, Princeton, NJ
28 August 1984	"Investigations to Reduce Noise and Increase Data Acceptance in GFDL's 4-D System" by William Stern, Geophysical Fluid Dynamics Laboratory, Princeton
4 September 1984	"Low Frequency Variability of Currents in the Tropical Atlantic Ocean" by Prof. R. Weisberg, North Carolina State University, Raleigh, NC
11 September 1984	"Quasi-Stationary Atmosphere Responses to SST Anomalies" by Dr. In-Sik Kang, Geophysical Fluid Dynamics Program, Princeton University, Princeton, NJ
12 September 1984	"Resonant and Turbulent Effects in Large Scale Flow over Topography" by Dr. Geoffrey K. Vallis, Scripps Inst. of Oceanography, La Jolla, CA

12 September 1984	"Large-Scale Aspects of the Coastal Ocean Response to Atmospheric Forcing off California and Oregon during April-August 1981" by Prof. John S. Allen, College of Oceanography, Oregon State University, Corvallis, OR
18 September 1984	"Ozone Measurement in the Southern Hemisphere" by Dr. Ian Galbally, CSIRO, Australia
19 September 1984	"A Massive Loss of Water from Venus: An Early Hot Ocean" by Dr. James B. Pollack, Theoretical Studies Branch, NASA/Ames Research Center, Moffett Field, CA
21 September 1984	"Modeling the Ice Ages" by Dr. Barry Saltzman, Dept. of Geology and Geophysics, Yale University
27 September 1984	"Evidence for Future Global Warming: How Large and When?" by Dr. James Hansen, Goddard Inst. for Space Studies, 2880 Broadway, NY

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APPENDIX E

Talks, Seminars, and Papers Presented Outside GFDL

During Fiscal Year 1984

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September-December 1983	Dr. S. Manabe "Modeling Study of Climatic Variation, Past, Present and Future" One of a series of 11 weekly lectures presented September through December, 1983. at the Geophysical Inst., University of Tokyo, Japan
3 October 1983	Dr. F. B. Lipps "The GFDL Cloud Model: Effect of Different Cloud Physics and Side Boundary Conditions", International Cloud Modelling Workshop, Aspen, Colorado
11 October 1983	Mr. Michael D. Cox "Ocean Modelling on the CYBER 205 at GFDL" NASA/GODDARD-CDC Symposium on CYBER 205 Applications" Lanham, Maryland
11 October 1983	Dr. Jerry D. Mahlman "A Middle Atmosphere View of the "Report of the Research Briefing Panel on Atmospheric Sciences" University Corporation for Atmospheric Research, Boulder, Colorado
17 October 1983	Mr. Joseph Sirutis "Subgrid Scale Parameterization in GCM's: Forecast Impact" Eighth Climate Diagnostics Workshop, Downsview, Ontario, Canada
17 October 1983	Dr. Kikuro Miyakoda "Experiments of Dynamic Monthly Forecasts" Eighth Climate Diagnostics Workshop, Downsview, Ontario, Canada
18 October 1983	Dr. Abraham H. Oort "Sea Surface Temperature Anomalies in the Equatorial Pacific Ocean and Global Climate Variations: Eighth Climate Diagnostics Workshop, Downsview, Ontario, Canada
20 October 1983	Dr. S. Manabe "Simulation of Atmospheric Variability" Inst. for Atmospheric Physics, Beijing, People's Republic of China
21 October 1983	Dr. S. Manabe "Simulation of Ice Age Climate" Inst. for Atmospheric Physics, Beijing, People's Republic of China
25 October 1983	Mr. William Stern "An Assessment of GFDL's Continuous Data Assimilation System used for Processing FGGE Data" Workshop on "Parameterization of Physical Processes in Moist Global Models of the Atmosphere" Air Force Geophysics Laboratory, Hanscom Air Force Base, Lexington, Mass.

28 October 1983	Dr. Richard Greatbach "The Sea Surface Temperature Response to a Storm", The National Hurricane Research Laboratory, Miami, Florida.
31 October 1983	Dr. Charles T. Gordon "A Scheme for Generation Radiatively Consistent, Effective Clouds at Two Atmospheric Levels" Fifth Conference on Atmospheric Radiation, Baltimore, Maryland
1 November 1983	Mr. Richard T. Wetherald "The Role of Cloud Feedback in the Sensitivity of Model Climate" Fifth Conference on Atmospheric Radiation, Baltimore, Maryland
1 November 1983	Dr. Kikuro Miyakoda "Long Range Prediction Based on Numerical Prediction Models" "Eighth Session of the Board on Atmospheric Sciences and Climate" National Academy of Sciences, Washington, DC
2 November 1983	Prof. George L. Mellor "The Coastal Upwelling Boundary Region", Seminar, Dept. of Geophysics, U. of Southern California, Los Angeles, California
3 November 1983	Prof. Jorge L. Sarmiento "Three-dimensional Ocean Models for Predicting the Distribution of CO_2 between the Ocean and Atmosphere" Oak Ridge National Research Laboratory, Knoxville, Tennessee.
8 November 1983	Prof. George L. Mellor "The Coastal Upwelling Boundary Region" Seminar, Dept. of Oceanography, Naval Postgraduate School, Monterey, California
11 November 1983	Dr. George Philander "The 1982/83 El Niño" Rutgers University, New Brunswick, New Jersey
14 November 1983	Dr. Kirk Bryan "Three Dimensional Oceanic Thermocline Models" New York University, Department of Applied Science, New York, New York
28 November 1983	Dr. Abraham H. Oort "Work on the Global Analysis of Climate in Progress at GFDL" National Center for Atmospheric Research, Boulder, CO

28 November 1983	Dr. Kikuro Miyakoda "Subgrid-Scale Parameterization in Global Models: Forecast Impact" European Center Medium-Range Weather Forecasts, Workshop on "Convection in Large-Scale Numerical Models" Reading, England
29 November 1983	Prof. George L. Mellor "The Coastal Upwelling Boundary Region" Seminar, Dept. of Oceanography, Oregon State University, Corvallis, Oregon
30 November 1983	Dr. Yoshikazu Hayashi "Confidence Intervals of a Climatic Signal and Predictability" Goddard Laboratory, Greenbelt, Maryland
1 December 1983	Dr. Kikuro Miyakoda "ABL Parameterizations in LRF and Climate Models" WMO/CAS Meeting of Experts on Atmospheric Boundary Layer Parameterization over the Ocean, Reading, England
6 December 1983	Prof. George L. Mellor "The Coastal Upwelling Boundary Region" American Geophysical Union Conference, San Francisco, Calif.
5 January 1984	Mr. Sydney Levitus "Annual Cycle of Temperature and Heat Storage in the World Ocean" Scripps Institute of Oceanography, La Jolla, California
10 January 1984	Dr. John R. Toggweiler "On the Control of Atmospheric pCO_2 by High Latitude Regions of the Ocean" AGU Chapman Conference on Natural Variations in Carbon Dioxide and Carbon Cycle, Tarpon Springs, Florida
10 January 1984	Dr. Yoshio Kurihara "On the Transformation of a Tropical Easterly Wave: A Simple Numerical Study" Fifteenth Technical Conference on Hurricanes and Tropical Meteorology of the AMS, Miami, Florida
10 January 1984	Mr. Robert E. Tuleya "The Formation of Comma Vortices in a Tropical Numerical Simulation Model" Fifteenth Technical Conference on Hurricanes and Tropical Meteorology, Miami, Florida
January 13, 1984	Dr. David Crisp "Dynamical Implications of the Mesospheric Radiative Drive" Seminar, Jet Propulsion Laboratory, Pasadena, California

January 25, 1984	Mr. Frank O. Bryan "Sensitivity of Ocean General Circulation Model Heat Transports to the Magnitude of Vertical Mixing" 1984 AGU Ocean Sciences Meeting, New Orleans, Louisiana
January 26, 1984	Dr. Kirk Bryan "Ocean Heat Transport" American Geophysical Union-ASLO Meeting, New Orleans, Louisiana
January 27, 1984	Dr. John R. Toggweiler "A Simple Model Solution for the Bomb Plutonium Maximum Observed in the Pacific Ocean" 1984 AGU Ocean Sciences Meeting, New Orleans, Louisiana
January 27, 1984	Prof. Jorge L. Sarmiento "A Seasonal Model of Sr-90 Uptake by the Oceans" 1984 AGU Sciences Meeting, New Orleans, Louisiana
January 27, 1984	Mr. Mitsuhiro Kawase "A Preliminary Description of the TTO Tropical Atlantic Study Upper Ocean Nutrients and Hydrography" 1984 AGU Ocean Sciences Meeting, New Orleans, Louisiana
February 8, 1984	Dr. Jerry Mahlman "Stratospheric Dynamics as Simulated by the GFDL 'SKYHI' General Circulation Model" Goddard Space Flight Center Laboratory for Planetary Sciences, Greenbelt, Maryland.
February 21, 1984	Dr. Raymond T. Pierrehumbert "Instability of Two-Dimensional Vorticity Distributions" Workshop on Vortex Dynamics, Los Alamos, New Mexico
February 22, 1984	Mr. David G. Dritschel "The Stability and Energetics of Co-Rotating Uniform Vortices" Vortex Dynamics Workshop, Los Alamos, New Mexico
February 27, 1984	Dr. George Philander "Simulation of the Seasonal Cycle in the Tropical Atlantic" FOCAL/SEQUAL Meeting, Paris, France
February 28, 1984	Prof. Jorge L. Sarmiento "On the Control of Atmospheric CO_2 by the High Latitude Surface Ocean" Courant Institute, New York University, New York, New York
March 2, 1984	Dr. Jerry D. Mahlman "Three-Dimensional Transport of Particulates" Meeting of the NAS/NRC Climate Research Committee "Study Session on the Climate Effects of Nuclear Explosions" Washington, DC

March 8, 1984	Dr. Boris Galperin "Simulation of Turbulent Flows and Turbulent Diffusion by Simple Turbulent Energy Model" Seminar, Department of Civil Engineering, Massachusetts Inst. of Technology Cambridge, Massachusetts
March 14, 1984	Dr. George Philander "Simulation of Low Frequency Variability in Tropical Oceans" University of Miami, Miami, Florida
March 21, 1984	Dr. Isaac M. Held "Stationary External Rossby Waves in Vertical Shear" Goddard Laboratory for Atmospheric Sciences/NASA, Greenbelt, Maryland
March 21, 1984	Dr. Ngar-cheung Lau "The Influences of Orography on Large-Scale Atmospheric Flows Simulated by a General Circulation Model" International Symposium on Tibetan Plateau and Mountain Meteorology, Inst. of Atmospheric Physics, Academia Sinica, Beijing, China
April 2, 1984	Dr. Kikuro Miyakoda "Recent Status of Long Range Forecasting Research at GFDL" WMO/CAS Working Group Meeting on Long Range Weather Forecasting Research, Geneva, Switzerland
April 5, 1984	Mr. Sydney Levitus "Global Estimates of Sea Surface Topography" Vertical Datum Meeting of the Vertical Datum Sub-Committee of the National Academy of Sciences, Washington, DC
April 5, 1984	Prof. Jorge L. Sarmiento "Tracer Models of Thermocline Ventilation" Harvard University, Cambridge, Massachusetts
April 9, 1984	Dr. Raymond T. Pierrehumbert "Local and Global Baroclinic Instability" Geophysical Fluid Dynamics Inst., Florida State University, Tallahassee, Florida
April 25, 1984	Prof. Jorge L. Sarmiento "A First Look at TTO Nutrient Measurements in the Main Thermocline" Woods Hole Oceanographic Inst. Woods Hole, Massachusetts
April 26, 1984	Prof. Jorge L. Sarmiento "On the Control of Atmospheric CO_2 by the High Latitude Surface Ocean" Woods Hole Oceanographic Inst. Woods Hole, Massachusetts

April 30, 1984	Prof. Jorge L. Sarmiento "On the Control of Atmospheric CO_2 by the High Latitude Surface Ocean" Texas A & M University, College Station, Texas
April 30, 1984	Dr. Isaac M. Held "Stationary External Rossby Waves in Vertical Shear" University of Washington, Dept. of Atmospheric Science, Seattle, Washington
May 1, 1984	Prof. Jorge L. Sarmiento "Trace Models of Thermocline Ventilation" and "Recent Results of Radium-226 and Radium-228 Measurements at Princeton" Texas A & M University College Station, Texas
May 2, 1984	Dr. Richard Greatbatch "Breaking Kelvin Waves and Solitary Rossby Waves in the Equatorial Oceans?" Department of Mathematics, University of Exeter, England
May 3, 1984	Dr. Yoshio Kurihara "Resolvability of Mesoscale" NMC Spring Lecture Series on Reginal Modeling, Washington, DC
May 3, 1984	Dr. George Philander "Air-Sea Interaction in the Tropics" Meeting on Air-Sea Interaction and TOGA, Liege, Belgium
May 5, 1984	Dr. Jerry D. Mahlman "Physics & Chemistry of the Atmosphere: Some Contemporary Issues" Chadron State College, Chadron, Nebraska
May 7, 1984	Dr. Abraham Oort "Observed Long-Term Variability in the Global Surface Temperatures of the Atmosphere and Oceans" CCCO/JSC Symposium on Coupled Atmosphere - Ocean Models, Liege, Belgium
May 7, 1984	Dr. Kirk Bryan "Transient Response of a Coupled Ocean-Atmosphere Model" World Climate Research Programme, Symposium on Coupled Ocean-Atmosphere Models, Liege, Belgium
May 14, 1984	Dr. Abraham Oort "Atmosphere, Oceans and the Rotation of the Solid Earth" Royal Netherlands Meteorological Institute, DeBilt, The Netherlands
May 16, 1984	Dr. Jerry D. Mahlman "Transport of Stratospheric Trace Constituents" American Geophysical Union Spring Meeting, Cincinnati, Ohio

May 18, 1984	Dr. Raymond T. Pierrehumbert "Local and Global Baroclinic Instability of Zonally Varying Flow" Massachusetts Inst. of Technology, Cambridge, Massachusetts
May 24, 1984	Dr. Jerry D. Mahlman "Report on Status of the U.S. Panel on MAP" N.A.S. Committee on Solar-Terrestrial Research Meeting, Washington, DC
May 27, 1984	Dr. George Philander "Oceanographic Aspects of El Niño" American Assoc. for the Advancement of Science Meeting, New York City, New York
May 29, 1984	Dr. Ngar-Cheung Lau "Response of a GFDL General Circulation Model to SST Fluctuations observed in the Tropical Pacific during the Period 1962-1976" Oceanic and Atmospheric Research Program Staff/NOAA, Rockville, Maryland
May 30, 1984	Dr. Syukuro Manabe "CO_2 and Climate" Fermi National Accelerator Laboratory, Batavia, Illinois
June 1, 1984	Dr. Hiram Levy II "Tropospheric O_3" A Comparison of Observation and Simulation" CEPP/Harvard University, Cambridge, Massachusetts
June 6, 1984	Dr. Bruce B. Ross "Impact of Enhanced Wind and Thermodynamic Information on Mesoscale Prediction" NCM Lecture Series, Camp Springs, Maryland
June 11, 1984	Dr. Jerry D. Mahlman "Remaining Failures in Stratosphere GCM Simulations" NASA -WMO Stratosphere Workshop, Starnberg, Germany
June 26, 1984	Dr. Isidoro Orlanski "Mesoscale Modeling and Predictability" NCAR Summer Colloquium on the Dynamics of Mesoscale Weather Systems, Boulder, CO
July 9, 1984	Dr. Kikuro Miyakoda "A Monthly Forecast Experiment: Preliminary Report Academy of Sciences FGGE Workshop, Woods Hole, MA
July 12, 1984	Dr. Stephen B. Fels and Mr. M. Daniel Schwarzkopf "Detailed Line by Line Calculations of H_2O and CO_2 Atmospheric Cooling Rates" ICRCCM Meeting, Greenbelt, MD

July 16, 1984	Dr. Raymond T. Pierrehumbert "Lee Cyclogenesis" AMS/NOAA Intensive Course on Mesoscale Meteorology, Boulder, CO
July 17, 1984	Dr. Bruce B.Ross "6-48 Hours: Numerical Weather Prediction" Mesoscale Meteorology and Forecasting Course, sponsored by NOAA/ERL, Boulder, Colorado
July 17, 1984	Dr. Isidoro Orlanski "Recent Discoveries in the Theory of Atmospheric Fronts" Goddard Laboratory for Atmospheric Sciences, NASA, Greenbelt, Maryland
August 15, 1984	Dr. Stephen B. Fels "Results of Standard Line-by-Line Calculations for H_2O and CO_2, and Comparisons with other GFDL Models" WMO Radiation Code Intercomparison Meeting, Frascati, Italy
August 20, 1984	Dr. Isaac M. Held "Stationary External Rossby Waves in Vertical Shear' and "Large-Scale Eddies and the General Circulation of the Troposphere" 'Visiting Scholars Program' of MIT/WHOI Graduate Students, Woods Hole, MA
August 22, 1984	Dr. Ngar-Cheung Lau "Response of a GFDL General Circulation Model to SST Fluctuations observed in the Tropical Pacific during 1962-1976" Workshop on Dynamics of Long Waves in the Atmosphere, Gothenburg, Sweden and "Comparison of GFDL and ECMWF Level 3-B FGGE Analyses" Global Diagnostics Seminar Helsinki, Finland
August 22, 1984	Dr. Stephen B. Fels "Scale-Dependent Radiative Damping in the Middle Atmosphere" International Radiation Commission Meeting, Perugia, Italy
August 23, 1984	Dr. Isidoro Orlanski "The Dynamics of Fronts" Polytechnic Institute, Paris, France
August 27, 1984	Dr. Raymond T. Pierrehumbert "Theoretical Results on the Forcing of Blocking by Transient Eddy Fluxes" Workshop on Global Scale Anomalous Circulation in the Atmosphere and Blocking, Rome, Italy
August 27, 1984	Dr. Isidoro Orlanski "Predictability of Mesoscale Phenomena" Centre de Recherche en Meteorologie, Paris, France

August 27, 1984	Dr. Stephen B. Fels "The Venus Semidiurnal Tide" Cambridge University, Cambridge, England
August 30, 1984	Dr. Isidoro Orlanski "Vortex-Fronts Interaction in Comma Clouds" Mini-Symposium on Polar Low, Copenhagen, Denmark
August 31, 1984	Dr. Raymond T. Pierrehumbert "Scattering of Rossby Waves from a Mountain Barrier" Atmospheric Science Group, University of Bologna, Bologna, Italy
September 2, 1984	Dr. Isidoro Orlanski "Predictability of Mesoscale Phenomena" Second International Symposium on Nowcasting, Norrhoping, Sweden
September 3, 1984	Mr. William F. Stern 1. "Continuous Data Assimilation at GFDL during FGGE" 2. "Investigations to Reduce Noise and Improve Data Acceptance in the GFDL 4-D Analysis System" European Centre for Medium-Range Weather Forecast Seminar/Workshop, Reading, England
September 12, 1984	Dr. George Philander "Predictability of Tropical Oceans and Atmospheres" Columbia University Center for the Study of Global Habitability, New York, NY
September 17, 1984	Dr. George Philander "Air-Sea Interactions in the Tropics" Meeting on the Southern Oscillation/El Niño Phenomenon, Paris, France

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APPENDIX F

List of Acronyms

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APPENDIX F

ACRONYMS

ALPEX	ALPine EXperiment
ANMRC	Australian Numerical Meteorology Research Centre
A2,E2,E4,F,M.	Five physical parameterization packages in use at GFDL, in increasing order of sophistication. E4 physics includes a high-order closure scheme for sub-grid turbulence, F physics includes Arakawa-Schubert convective parameterization, and M physics include envelope orography.
CODE	Coastal Ocean Dynamics Experiment
ECMWF	European Centre for Medium-Range Weather Forecasting
FGGE	First GARP Global Experiment- Dec.1978 - Nov.1979 IIIb - Data set analyzed on a spatial grid. 4D- Analysis system taking into account both space and time variation of the data. SOP1 - First Observing Period, Jan.5 - Mar.5,1979 SOP2 - Second Observing Period May 1 - June 30, 1979
GARP	Global Atmospheric Research Program
GCM	General Circulation Model
HIBU	Hydrological Institute, Belgrade University
MAC/BES	Meso-alpha coarse model/meso-Beta scale model
MCS	Mesoscale Convective System
Meso α, β, or γ	Three classes of mesoscale atmospheric motion, in descending order of spatial scale.
NOS	National Ocean Service
NMC	National Meteorological Center (USA)
SESAME	Severe Storms & Mesoscale Experiment
SST	Sea Surface Temperature
TTO	Transient Tracers in the Ocean
WOCE	World Ocean Circulation Experiment

U.S. GOVERNMENT PRINTING OFFICE: 1983—576-000/20,001 REGION NO. 8